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THE ENGINEERING APPROACH. USE OF SIMPLE QUANTITATIVE ANALYSES.

By LT. COMMANDER R. E. W. HARRISON, U.S.N.R.

Methodical thought processes are at present denied to many people in all walks of life, the result being seen in reliance on emotionalism, hunches, incomplete analysis, theatricalism, and the use of just plain ordinary sloppily incomplete data. All human problems, whether they be the engineering design of a bridge, the defeating of an opposing army, the destruction of enemy ships, or the solution of a simple task such as the selection of a person for promotion, yield to analytical treatment; this article is a plea for the teaching of methods of analysis to all students as a part of their formal education.

The attitude taken by some college professors, that by the time the student has reached college age he has already learned how to

think, is dead wrong and the answer to this is that those professors themselves have never made use of methodical quantitative analysis to anything other than the routine educational tasks in physics, geometry, and mathematics.

All life yields to analysis, and the reason we have so many unanswered queries is that we do not know how to use the mental tools which now lay close at hand, available to anyone with the mental strength to use them.

Sound judgment, as applied to all things in respect to which judgment is called for, should invariably be analytically approached, with the conclusion cooly and calmly arrived at, if the results are to be truly judicial. The ability to achieve this end is desired by every person of discrimination. Unfortunately, relatively few people have been trained, or have taken the trouble to train themselves, in the few simple, basic, quickly applied methods of analysis which are available for immediate use to any person with an elementary education. The charge can be made and upheld, that there is a deficiency in any educational system, no matter how adequate otherwise, which fails to teach a student how he can so arrange his windows of intellectual enlightenment that the pattern of light focuses clearly on a conclusion which is self-evident, inescapable, logical, and wise.

An indecisive person is a liability rather than an asset in any organization, irrespective of whether the organization be an army in the field, a division of battleships, a factory, a federal government, or even that smallest unit of organization, a family of human beings. Probably one of the most richly rewarded fields of psychoanalysis lies in the diagnosis and supplying of mental formulae which will provide a life line permitting the indecisive person to make decisions in which he has confidence and conviction.

Method of Thought.

With an accepted pattern for attack on all problems, tried out and proven effective, the average person can at once pick out an appropriate trial analyses chart, fill in the factors, apply the rules of exception and weighting, and automatically and systematically arrive at a conclusion which is logical, legal, equitable, and lasting.

Imagination Needed to Provide List of Factors.

Education is the great provider of the "windows" through which the light of other people's experiences may be brought to bear upon one's own particular problems. Education may be formal, informal, technical, non-technical, can—in fact—be most anything so long as it is broad and has been developed through the "seeing eye" of the receptionist without prejudices borne in, plus a retentive memory. Obviously, the broader the education, the more windows through which the light can be admitted; it is a worth-while matter of record which we may credit to today's educational procedures, that formal education now aims at providing the student with a good kit of "know how"; "know where to look"; and "know people"; and the proper references, rather than the provision of such isolated relatively useless data as the cosine of this or that angle; the chemical constituents of this or that mineral, at the expense of the knowledge of where to get the proper data quickly and accurately, and how to apply it once it has been obtained.

How often is the thought thrust on the adult mind, that the formal education of our youth has, in most cases, neglected to include proper grounding in the basic principles from which there is no escape for anyone. It is surprising today to encounter so many technicians who have achieved such success as has been theirs, armed with a kit of tools, dull of edge, and incapable of easy use, unco-ordinated, and rusty from disuse.

Invariably, at the head of any large organization there is an exponent of the application of the few basic principles which run the activities of that organization. If further proof of this thesis be needed, it lies in the fact that all the truly great individuals of all times have had simple methodical thought processes which have adequately upheld the mission of their minds, on those occasions when they have successfully achieved that which they most desired, often in the face of seemingly insurmountable difficulties.

Available Time.

Just as the timid recruit requires much time, much applied patience, repeated instruction in the creation and boosting of his morale, and the availability of a good rifle and fine weather before

he can begin to make a score on the rifle range, so the average person requires a host of factors operating in his favor, before he can attain results in the mental field. That which appears to be super mental agility in some one person often is simply the exposition of a training formula patiently imparted by a competent instructor.

Why it should ever have been thought that one might possess mental agility without organized preparation and practice is another demonstration of a short-sighted unwillingness or inability to think in a trained way which characterizes many a youth as he bravely steps forth into the cruel waiting world from out of the hands of his equally or even more muddled preceptors. If our professors and other educators could perceptively peruse, in reverse order, the vista of their own lives, they would have a much better appreciation of the circumstances and factors which taught them how to learn at the time when they first struggled with the problems with which they now bedevil their charges. This is all the more apparent when one recalls how even the boxing instructor invariably commences his instructional remarks by impressing on the student that failure to take such and such a guard at sometime or other results in taking a fatal wallop. Reverting to the educational theme, it is surprising that so little of modern history is enlightened by authentic dissertations on past circumstances which have made the situation of today inevitable. It might be said that the tendency of practically all human beings is to be mentally lazy and emotional, rather than mentally alert and factually analytical. The follower of hunches is the demonstration par excellence of today's mental processes. History, however, fails to relate that the followers of hunches have, so far, beaten the analyst—that they have accumulated large fortunes on the race track the stock exchange, or even in mundane business. That so many people play their hunches, rather than their judgment, is additional proof, if that indeed be needed, that mental laziness and the conceit which prompts faith in the starry eyed goddess of fickle fortune is but another phase of autointoxication.

Universal Application.

There will always be those rugged individuals who oppose standardization of anything, in the honest belief that standardiza-

PROBLEM:- CHOOSING A NEW CAR

THE QUALITY CHART

A COMPARISON OF "ALL THREE" LOW-PRICED CARS WITH LEADING HIGH-PRICED C

HERE'S HOW "ALL THREE" LOW-PRICED CARS COMPARE IN THE 22 IMPORTANT FEATURES FOUND IN HIGH PRICED CARS CAR "1" HAS 21 CAR "2" HAS 9 CAR "3" HAS 7	1. 117-INCH, OR LONGER, WHEELBASE	2. HYDRAULIC BRAKES	3. L-HEAD ENGINE DESIGN	4. ALUMINUM ALLOY PISTONS	5. FOUR RINGS PER PISTON	6. CHAIN CAMSHAFT DRIVE	7. AUTOMATIC CHOKE	8. PRECISION-TYPE CRANKSHAFT CONNECTING ROD BEARINGS	9. PRESSURE LUBRICATION OF LOWER CONNECTING ROD BEARINGS	10. VALVE TAPPET ADJUSTMENT	11. ROLLER BEARINGS ON TRANSMISSION COUNTERSHAFT	12. FOUR CHASSIS SPRINGS	13. INDEPENDENT FRONT WHEEL SUSPENSION	14. ROLLER BEARI... UNIVERSAL	15.
$ 2895 CAR	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
$ 2595 CAR	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
$ 1594 CAR	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
LOWEST PRICED CAR "1"	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES
LOWEST PRICED CAR "2"	NO	YES	NO	NO	NO	NO	NO	NO	NO	YES	NO	YES	YES	YES	YES
LOWEST PRICED CAR "3"	NO	YES	YES	NO	NO	NO	NO	YES	YES	NO	YES	NO	NO	NO	NO

SIMPLEST FORM OF COMPARITIVE A

NOTE :- NO VALUES OR WEIGHTINGS HAVE BEEN ASSIGNED TO FEATURES —— HENCE CONCLUSIONS ARRIVED AT CAN VERY EASILY BE ERRONEOUS.

BASIS OF ANALYSIS IS EXCELLENT IN CONCEPT, BUT BUYER MUST SELECT WEIGHT VALUES AND ASSIGN THEM TO

ANALYSIS CHART NO. I

ADVERTISING MATTER

HART

H-PRICED CARS IN QUALITY FEATURES

...ERNHART	...ASSIS SPRINGS	13. INDEPENDENT FRONT WHEEL SUSPENSION	14. ROLLER BEARING UNIVERSAL JOINTS	15. HYPOID REAR AXLE	16. TAPERED ROLLER DIFFERENTIAL BEARING	17. NOTCHLESS DRIVE	18. RUST-PROOF BODY	19. OIL BATH AIR CLEANER	20. SEALED BEAM HEADLAMPS	21. FLOATING-TYPE OIL INTAKE	22. CHOICE OF COLORS AT NO EXTRA COST	TOTAL
ES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES		22
ES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES		22
ES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES		21
ES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES		(21)
ES	YES	YES	NO	NO	YES	NO	YES	NO	YES			(9)
O	NO	NO	YES	NO	NO	NO	YES	NO	NO			(7)

RITIVE ANALYSIS

THEM TO EACH OF THESE FEATURES.

PROBLEM:- ORGANIZING A DELIVERY SCHEDULE.

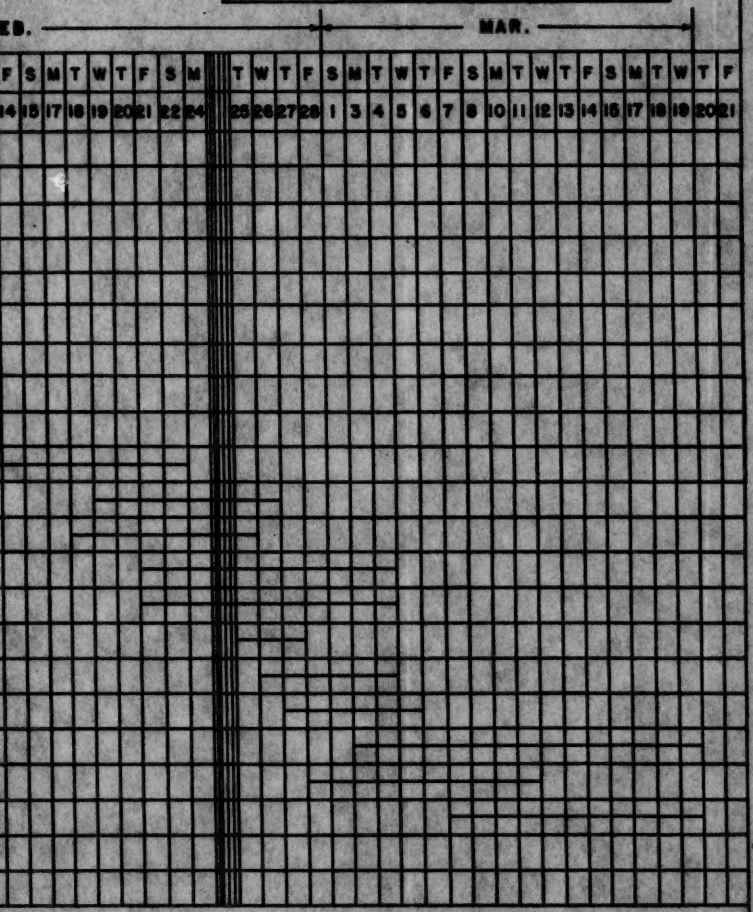
DAYS ALLOWED		JAN. F 17	S 18	M 20	T 21	W 22	T 23	F 24	S 25	M 27	T 28	W 29	T 30	F 31	S 1	M 3	T 4	W 5	T 6	F 7	S 8	M 10	T 11	W 12	T 13	F 14	S 15	M 17	T 18	W 19
4	WALL EXCAVATION																													
3	SEWER AND DRAIN EXC.																													
3	COLUMN FOOTINGS																													
2	POUR FOOTINGS																													
5	FOUNDATION FORMS																													
2	POUR WALLS & COLUMNS																													
5	GRADING FOR FLOOR																													
8	POUR FLOOR																													
5	REMOVE STEEL SASH																													
11	STEEL ERECTION																													
7	BRICK WORK																													
7	STEEL DECK ERECTION																													
10	INSULATION & ROOFING																													
10	SHEET METAL																													
3	SASH ERECTION																													
6	GLAZING																													
6	WOOD BLOCK FLOOR																													
15	PAINTING																													
10	HEATING																													
11	ELECTRIC WIRING																													
	TEMPERATURE																													
	WEATHER																													

THIS CHART PROVIDES AN ANALYSIS BASED ON REQUIRED TIME TO ACCOMPLISH
BE CONSECUTIVELY ORGANIZED AND COMPLETED IN A PREDETERMINED ORDER.

THIS IS A SIMPLE AND ACCURATE METHOD OF PLANNING AND THE CHART LEN
YARDSTICK OF PERFORMANCE.

IN THIS CASE THE ELEMENTS UNDER CONTROL ARE DATE OF COMMENCEMENT A
CAN BE USED EASILY TO CONTROL THE WORK SEQUENCE OF SEVERAL THOUSAND M

ANALYSIS CHART NO. 2



COMPLISH A SEQUENCE OF BUILDING OPERATIONS WHICH MUST
ORDER.

ART LENDS ITSELF TO USE AS AN EASILY UNDERSTOOD

EMENT AND DATE OF FINISH AND A SIMPLE CHART OF THIS TYPE
OUSAND MEN ENGAGED ON A BUILDING PROJECT.

PROBLEM:- SELECTING A MACHINE TOOL.

MACHINE TOOL MERIT ANALYSIS.

FEATURE:-	PRICE	WEIGHT	DELIVERY	POWER TRANSMISSION	REPUTATION IN YARDS	VALUE OF MECHANICAL FEATURES	INITIAL ACCURACY	DURABILITY OF ACCURACY (10 YEARS)	SIZE OF SPINDLE BEARINGS	TYPE
WEIGHT - % HEAVY DUTY LATHES.	10	5	20	21/2	5	7 1/2	5	15	5	5
% 67 1/2 R = RECORD	R	R	R	R			R		R	R
% 32 1/2 O = OPINION					O	O		O		
BIDDERS										
A										
B										
C										
D										
E										
F										
G										
H										

RULES:— MATTERS OF RECORD = BE ACCURATE
" " OPINION = " " & IMPARTIA

EVALUATE:— POWER TRANSMISSION ON % EFFIC
REPUTATION IN YARDS ON CAREFU
INITIAL ACCURACY ON MANUFA
DURABILITY OF ACCURACY ON CAREFU
DEMONSTRATOR HELP ON "
QUALITY OF CUSTOMER LIST ON "
" " MFR'S. SHOP ON ACTUAL

THE COMPARATIVE ANALYSIS OUTLINED IN THIS CHART IS BASED ON FEATURES OF M
MANUFACTURERS. IT WILL BE NOTED THAT ALMOST 70 % OF THE "WEIGHTING" IS A
OF INFORMED OPINION.

USE OF THIS TYPE OF CHART IN DEALING WITH THIS TYPE PROBLEM ENTAILS THE
TO EACH FACTOR. THIS IS A RESPONSIBILITY WHICH CANNOT BE ESCAPED. HOWE
CIRCUMSTANCES CHANGE.

ANALYSIS CHART NO. 3

ALYSIS.

OF SPINDLE BEARINGS	TYPE OF BEARING	FINISH OF MACHINE	EQUIPMENT OVER MINIMUM	DEMONSTRATOR HELP	CHIP DISPOSAL	QUALITY OF CUSTOMER LIST	QUALITY OF MFR'S. SHOP	SCORE
	5	21/2	21/2	21/2	5	21/2	5	100%
	R		R	R	R			
		0				0	0	

IMPARTIAL
%. EFFICIENCY.
CAREFUL CHECK UP.
MANUFACTURER'S TEST SHEETS.
CAREFUL CHECK UP.
" " "
ON " " "
ACTUAL KNOWLEDGE.

URES OF MERIT PLOTTED AGAINST A GROUP OF SELECTED
ITING" IS A MATTER OF RECORD AND ONLY 30% IS A MATTER

TAILS THE RESPONSIBILITY OF ALLOCATING WEIGHT OR SCORE
ED. HOWEVER, ONCE DONE IT HOLDS GOOD UNTIL THE BASIC

PROBLEM:- TO SELECT A SOAP.

ANALYSIS CHART NO. 4

QUESTION:	ANSWER FOR YOUR PRESENT SOAP	ANSWER FOR X SOAP
1 DOES THE SOAP PROVIDE AN "ACTIVE," THOROUGH-CLEANSING LATHER?		YES. X SOAP GIVES YOU RICH, CREAMY, GENTLE LATHER, ACTIVE AND THOROUGH IN ITS CLEANSING.
2 DOES THE SOAP HELP GUARD AGAINST BODY ODOR?		YES. THOROUGH CLEANSING WITH X SOAP TO REMOVE DIRT AND PERSPIRATION, IS A SURE WAY TO KEEP SKIN SWEET AND FRESH.
3 IS THE SOAP ARTIFICIALLY TINTED?		NO. X SOAPS OLIVE COLOR IS NATURAL IT COMES ONLY FROM OLIVE AND PALM OILS WITH WHICH IT IS MADE . . . . . NOTHING ELSE.
4 DOES IT FLOAT?		NO. AIR IN SOAP MAKES IT FLOAT, X SOAP IS ALL SOAP..." FRENCH-MILLED"... SOLID TO THE LAST FRAGRANT WAFER. SO X SOAP DOESN'T FLOAT.
5 IS IT RIGHT FOR YOUR BATH?		YES... MADE ONLY FOR THE CARE OF LOVELY SKIN, X SOAP IS YOUR LOGICAL CHOICE FOR "THAT SCHOOLGIRL COMPLEXION ALL OVER!"
6 IS IT RIGHT FOR YOUR BABY'S DELICATE SKIN?		YES. X SOAP IS SO SAFE, SO PURE, IT WAS CHOSEN EXCLUSIVELY FOR THE SENSITIVE SKIN OF THE FAMOUS DIONNE QUINTUPLETS.
7 IS IT A SOAP YOUR MENFOLK WILL LIKE TO USE?		YES. MEN LIKE X SOAPS THICK, QUICK LATHER, THE PLEASING AFTERGLOW OF ITS THOROUGH, GENTLE CLEANSING. GET THE NEW MAN-SIZE, BATH SIZE.

7 IS IT A SOAP YOUR MENFOLK WILL LIKE TO USE?		YES. MEN LIKE XSOAPS THICK, QUICK LATHER, THE PLEASING AFTERGLOW OF ITS THOROUGH, GENTLE CLEANSING. GET THE NEW MAN-SIZE, BATH SIZE.
8 IS IT MADE WITH OLIVE AND PALM OILS?	NO. NO OTHER LEADING BEAUTY SOAP IS MADE WITH OLIVE AND PALM OILS . . . NATURE'S FINEST BEAUTY AIDS.	YES. XSOAP IS MADE WITH OLIVE AND PALM OILS ALONE — THE COSTLIEST OIL BLEND USED FOR ANY LEADING SOAP.
9 HOW MUCH OLIVE OIL GOES INTO THE MAKING OF A SINGLE CAKE?	NONE. NOT A SINGLE DROP. MOST OTHER LEADING SOAPS ARE MADE WITH ANIMAL FATS — BLEACHED OR TINTED.	3½ TEASPOONFULS OF OLIVE OIL — THINK OF IT! — GO INTO THE MAKING OF EVERY CAKE OF XSOAP.
10 IS IT FIRST CHOICE OF WOMEN FOR BEAUTY CARE?	NO. ONLY ONE SOAP CAN CLAIM THAT POPULARITY. IT IS XSOAP.	YES. IN EVERY CLIMATE, FOR OILY SKINS AS WELL AS DRY, WOMEN HAVE MADE XSOAP THE LARGEST SELLING BEAUTY SOAP IN THE WORLD.

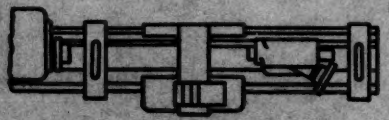
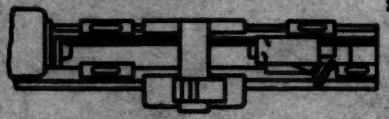
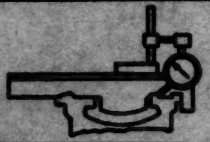
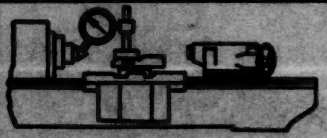
HERE AGAIN AN EFFORT IS MADE TO EDUCATE THE PUBLIC IN THE USE OF A SIMPLE FORM OF ANALYSIS.

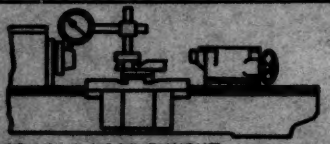
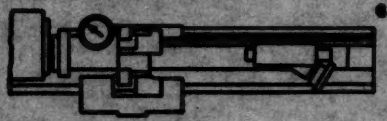
THE VALUE OF THIS CHART IS DEBATABLE AS THE "WEIGHTING" OR IMPORTANCE OF FACTORS 1 TO 7 HAS BEEN AVOIDED AND THE BUYER IS LEFT WITH THE ASSUMPTION THAT EACH FACTOR IS OF EQUAL IMPORTANCE, A FACT WHICH WILL NOT STAND ANALYSIS FOR TWO CONSECUTIVE SECONDS.

STANDARDS OF ACCURACY, LATHE GROUP N.M.T.B.A.

PROBLEM:- SELECTING TYPE OF LATHE REQUIRED TO PRODUCE A PREDETERMINED DEGREE OF ACCURACY (TECHNICAL).

ANALYSIS CHART NO. 5

TEST	RECOMMENDED STANDARDS		
	TOOL ROOM LATHES	12" TO 18" INCLUSIVE ENGINE LATHES	20" TO 36" INCLUSIVE ENGINE LATHES
1  BED LEVEL - TRANSVERSE DIRECTION	WHEN USING PRECISION LEVEL, BOTH READINGS TO BE WITHIN .0005 IN 12 INCHES	WHEN USING PRECISION LEVEL, BOTH READINGS TO BE WITHIN .0005 IN 12 INCHES	WHEN USING PRECISION LEVEL, BOTH READINGS TO BE WITHIN .001 IN 12 INCHES
2  BED LEVEL - LONGITUDINAL DIRECTION	WHEN USING PRECISION LEVEL ALONG BED MAXIMUM READING TO BE WITHIN .0005 IN 12 INCHES.	WHEN USING PRECISION LEVEL ALONG BED MAXIMUM READING TO BE WITHIN .0005 IN 12 INCHES.	WHEN USING PRECISION LEVEL ALONG BED MAXIMUM READING TO BE WITHIN .001 IN 12 INCHES.
3  TAILSTOCK WAY ALIGNMENT	MAXIMUM READING ALONG LENGTH OF BED .0005 IN 48 INCHES.	MAXIMUM READING ALONG LENGTH OF BED .00075 IN 48 INCHES.	MAXIMUM READING ALONG LENGTH OF BED .001 IN 48 INCHES.
4  SPINDLE CENTER RUNOUT	TOTAL INDICATOR READING 0 TO .0004.	TOTAL INDICATOR READING 0 TO .0005.	TOTAL INDICATOR READING 0 TO .00075.
5			

SPINDLE CENTER RUNOUT			
 SPINDLE NOSE RUNOUT	TOTAL INDICATOR READING 0 TO .0003.	TOTAL INDICATOR READING 0 TO .0004.	TOTAL INDICATOR READING 0 TO .0006.
 CAM ACTION OF SPINDLE	TOTAL INDICATOR READING WITH INDICATOR ON REAR SIDE OF TEST PLATE 0 TO .0003.	TOTAL INDICATOR READING WITH INDICATOR ON REAR SIDE OF TEST PLATE 0 TO .0005.	TOTAL INDICATOR READING WITH INDICATOR ON REAR SIDE OF TEST PLATE 0 TO .00075.

THE TECHNICAL ANALYSIS OUTLINED ON THIS CHART MAKES AVAILABLE IN SIMPLE TABULATED, EASILY SELECTIVE FORM, INFORMATION ON WHICH AN EXTREMELY IMPORTANT DECISION CAN BE BASED.

ALL THAT IS REQUIRED IS FOR THE SELECTOR TO DETERMINE THE DEGREE OF ACCURACY REQUIRED AS REVEALED ON THE DRAWINGS OF THE WORK PROBLEM AND TO THEN SELECT FROM THIS CHART A MACHINE WHICH WILL EQUAL OR BETTER THESE REQUIREMENTS.

PROBLEM :- SELECTING THE BEST METHOD OF MANUFACTURING A PROJECTILE (BASIC OPERATION OF FORGING OR FABRICATING).

METHOD	RATE OF PRODUCTION	ACCURACY OF FORGING	COST OF EQUIPMENT	COST OF TOOL UPKEEP	% LOS IN SCR
UPSETTER					
HYDRAULIC PRESS					
TUBING					
WELDING					
MULTIPLE PUNCH PRESS					
MECHANICAL PRESS					
CASTING					
ANY OTHER METHOD					

IN THIS CHART THE VARIOUS AVAILABLE METHODS OF FABRICATION ARE LISTED I
QUALIFICATIONS ARE TABULATED IN ADJOINING COLUMNS. BY PLOTTING THE APPRO
ULTIMATE DECISION AS TO WHICH PROCESS TO USE BECOMES AUTOMATICALLY AP
VISIBLE AND LASTING EVIDENCE THAT THE WHOLE PROBLEM HAS BEEN SURVEYED

ANALYSIS CHART NO. 6

	% LOST IN SCRAP	COST OF PRODUCT	TOTAL COST PER 1000	TECHNICAL ACCEPTABILITY

LISTED IN THE LEFT-HAND COLUMN AND THE APPROPRIATE
THE APPROPRIATE INFORMATION AGAINST EACH PROCESS, THE
ICALLY APPARENT AND THE ANALYSIS IN THIS FORM PROVIDES
SURVEYED IN ITS ENTIRETY PRIOR TO ACTION BEING TAKEN.

tion freezes initiative, and that standardization of methods of thought analyses will in a short time atrophy the brain. Fortunately, these poor people are in the minority, and although they make up in volume with their howls of protest, for their lack of judicial merit, they usually go down to utter defeat before the insatiable craving of the healthy young mind forever seeking a reliable and trusted ladder on which he may climb to greater heights of independent thinking in the shortest time and with the least effort.

The mission of this article is a plea for a more anayltical approach to all of our mutual problems, whether they be professional or lay in nature, domestic or foreign, religious or social; whether they concern our health, our politics, or our price.

To the end that this contribution may be deemed demonstrated, a few typical analyses are presented here. It will be noted that the analyzer is called on to evaluate the composite factors in each case, and in the author's opinion this is a responsibility no individual can ever shirk, no matter how hard or distasteful the task of proportionate evaluation may be. Here is where the real strength of character is developed, which, when in evidence permits the person concerned to execute his decisions in accordance with a well thought out plan.

To those who devote adequate thought to this subject, it is a matter of surprise that the philosophy of logic has so far found so little favor among those whose real task is to teach us "how to think." Perhaps it is that our preceptors fear the effect on the student mind when the time-honored opaque crusts of prejudice; out-worn theories, based on incomplete data; hit or miss methods and motivations, based on hunches are at last broken down and revealed in the light of their true worth. Possibly new methods of imparting knowledge are required.

Conclusion.

Contemplation from the philosophic viewpoint alone, insufficiently stirs the imagination to proper appreciation of quantitative analysis as an everyday tool for the hands of "John Doe." In the beginning, it takes much mental strength to compel the reluctant mind to arrange its data on cause and effect in an orderly way,

but once the technique has been acquired, the practice loses all its terrors and, in a short time, there even occurs a warm feeling of beneficent pride after a good piece of practical analysis has been accomplished in much the same way we all, in our pre-school days, experienced a sense of beatification when nurse commended us for a good job done in obeying one of the primary laws of the nursery.

In other words, that which is advocated is an orderly method of thought, a habit which can be just as easily acquired as any of the other habits which make up the trivia and minutia of everyday life.

"Mr. Milquetoast" normally shuns a discussion on current national economic problems unless sure of the intellectual inferiority of his audience. "Mrs. Milquetoast" issues no brash challenges to mortal intellectual combat with fellow members of the Mothers' Club. Why? Because they both lack the conviction and poise inseparable from the analytical mind.

To begin with, the suggestion is offered that the subject's normal mental processes be relied on for the everyday affairs of life, and quantitative analysis be reserved only for the more important questions. Gradually, the sure-fire results and fascinating processes of constructive analytical thought will enchant the mind of even the dullest operator, and so, in course of time, there will be achieved that ideal of democracy, a clear thinking, independently minded public.

Concurrently, our analytically minded public will see with new eyes, and will hear with new ears, the gaudily deceptive advertising and clap-trap of many of the radio programs. They will also be able to defeat the man at the county fair who now beats them to what appears to be a cinch—they can not pick out the answer to "under which shell does the dime repose?" How, you ask will they beat it? Why, by simply walking away and perhaps wasting their money on something else.

These thoughts are a plea for the application of quantitative analysis to the problems of everyday life. Far be it from the author's intention to suggest the use of quantitative analysis in the evaluation of matters which are essentially spiritual, artistic,

or matters of affection. In cases of such nature we must evaluate the intangibles and that is not easy, but also not impossible.

If any master military mind opines that time, place, and opportunity are always lacking wherewith and wherein to make an analysis of a projected five paragraph operation order, there is offered in refutation of this theory the proof that every unsuccessful military action has upon subsequent analysis been shown to be faulty in concept simply because the analysis was made after and not before the order was issued.

There is no such thing as mathematical certainty in any phase of this or the next life, but the law of averages inspires the dictum of the gods and until we are blessed with divine inspiration we had better make good and systematic use of the tools which are always to be found close at hand.

A case has been presented here which merits attention especially in this time of stress and strain. There never has been an occasion when our decisions were of greater potency—this plea is that we make them good and sound in every way.

A NEW METHOD FOR CHECKING PROPELLERS.

By Lewis H. Kenney, B.S., M.E., Civil Member.

Propeller Designs, for many years, required that the "driving" or "pressure" faces of propellers should be helicoidal surfaces. These surfaces are generated by a right line revolving around an axis and advancing along it at uniform rates. The generatrix rotates parallel to a directing plane or cone, as the designer may select, and the distance it advances along the axis during one complete revolution is called the pitch of the surface.

To machine a helicoidal surface is a relatively simple matter. It is only necessary to place the propeller on a turntable and provide a mechanism which will cause it to rotate by predetermined increments. The cutting edge of the tool must be guided to move in a right line which passes through the axis of the propeller and to move vertically by predetermined increments. The angular increments are so proportioned to the vertical increments that the designed pitch is obtained. The reciprocating tool mechanism operates both increment feeds. The propeller must be so positioned that the path of the cutting tool will be along a position of the generatrix. With the machine so set, the cutting tool reproduces the successive positions of the generatrix.

After the machining operation has been completed, the tool marks are removed and the surface finished. A pitchometer is usually applied to check the pitch and obtain data for record. If the essential mechanisms of the machine have been correctly computed and set, the application of the pitchometer is unnecessary to measure pitch. The helicoidal surface or the "pressure face" provides a convenient base from which to measure blade thicknesses, and the "suction face" contours to determine conformity with design.

With the introduction of the hydrofoil form of propeller blade,

it became necessary to devise some other method for finishing the blades because there was no machine available which could perform the required operations. It was also necessary to develop a method for determining the extent of the work to be done on the castings and also to check the finished product.

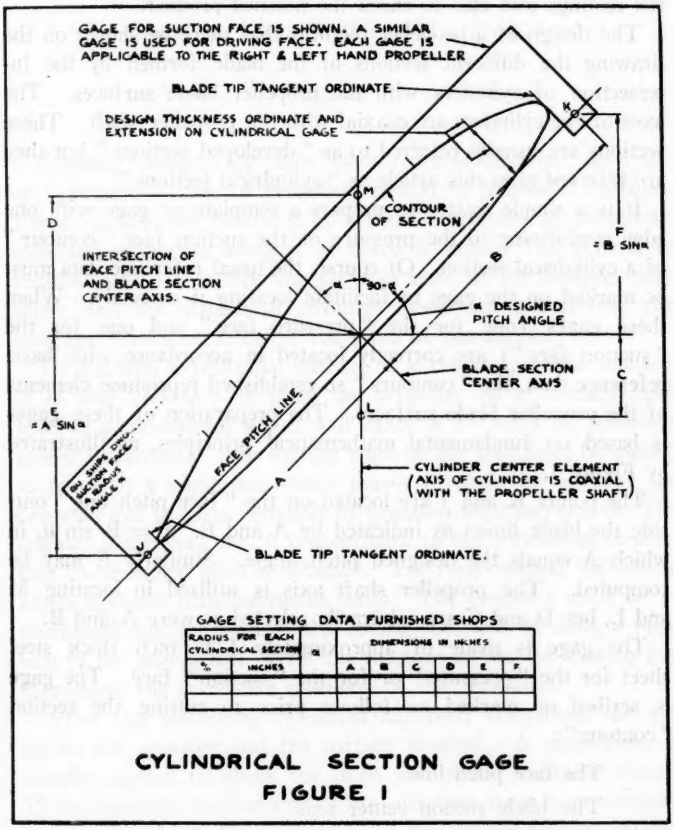
The design of a propeller requires that there be shown on the drawing the different sections of the blade formed by the intersection of cylinders with the propeller blade surfaces. The axes of the cylinders are coaxial with the propeller shaft. These sections are usually referred to as "developed sections" but they are referred to in this article as "cylindrical sections."

It is a simple matter to prepare a template or gage with one edge conforming to the pressure or the suction face "contour" of a cylindrical section. Of course, the usual reference data must be marked on the gage to facilitate locating it correctly. When these gages (one for the "pressure face" and one for the "suction face") are correctly located in accordance with basic reference data, the "contours" so established reproduce elements of the propeller blade surfaces. The preparation of these gages is based on fundamental mathematical principles, as illustrated by Figure 1.

The points K and J are located on the "face pitch line" outside the blade limits as indicated by A and B. $F = B \sin \alpha$, in which A equals the designed pitch angle. Similarly E may be computed. The propeller shaft axis is utilized in locating M and L, but D and C are arbitrarily selected as were A and B.

The gage is made of approximately 1/32 inch thick steel sheet for the "pressure" or for the "suction" face. The gage is scribed or marked as follows prior to cutting the section "contour":

The face pitch line
The blade section center axis
The angle α
Points K, J, M, and L
Design thickness ordinates extensions
Pressure or suction face
Drawing No. Cylindrical Section Radius


GAGE FOR SUCTION FACE IS SHOWN. A SIMILAR GAGE IS USED FOR DRIVING FACE. EACH GAGE IS APPLICABLE TO THE RIGHT & LEFT HAND PROPELLER
BLADE TIP TANGENT ORDINATE
DESIGN THICKNESS ORDINATE AND EXTENSION ON CYLINDRICAL GAGE
CONTOUR OF SECTION
INTERSECTION OF FACE PITCH LINE AND BLADE SECTION CENTER AXIS.
α DESIGNED PITCH ANGLE
BLADE SECTION CENTER AXIS
FACE PITCH LINE
CYLINDER CENTER ELEMENT (AXIS OF CYLINDER IS COAXIAL WITH THE PROPELLER SHAFT)
BLADE TIP TANGENT ORDINATE.
D
E = A SIN α
F = B SIN α
A
B
C
90-α
GAGE SETTING DATA FURNISHED SHOPS
RADIUS FOR EACH CYLINDRICAL SECTION
α
DIMENSIONS IN INCHES
% INCHES
A B C D E F

CYLINDRICAL SECTION GAGE
FIGURE 1

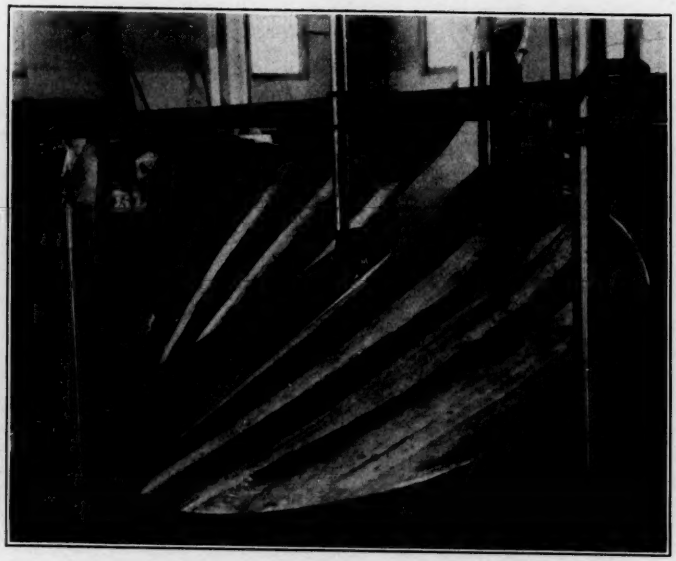


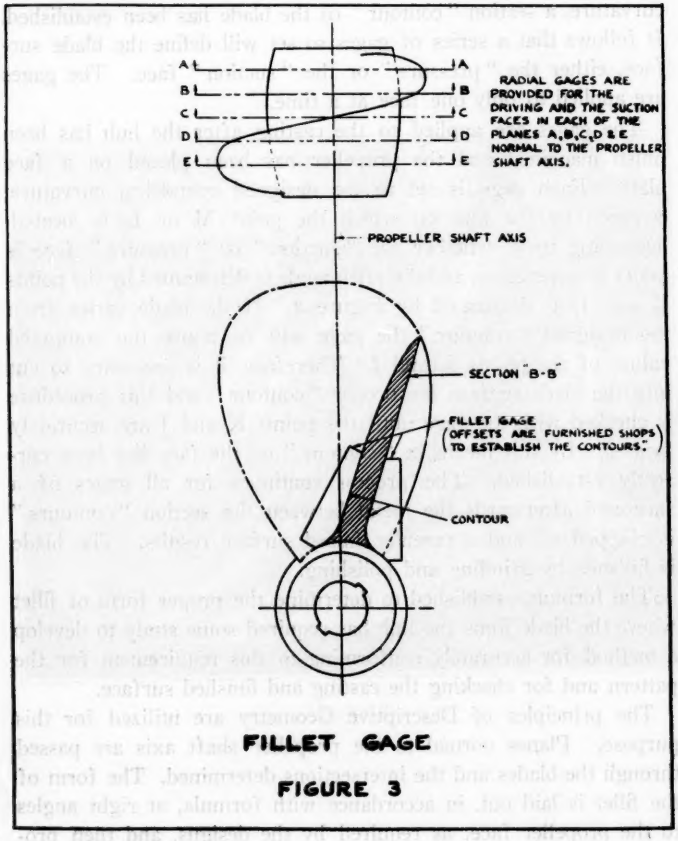
FIGURE 2.

It is evident from the foregoing that, if the gage is so set that the points M, K, and J, or points L, K, and J are correctly located, as given in the "gage setting data" tabulation which is issued for each propeller design and with the correct cylindrical curvature, a section "contour" of the blade has been established. It follows that a series of gages so set will define the blade surface, either the "pressure" or the "suction" face. The gages are applied to only one face at a time.

The gages are applied to the casting after the hub has been finish machined and the propeller has been placed on a face plate. Each gage is set to the designed cylindrical curvature, centered by the line on which the point M or L is located, depending upon whether the "suction" or "pressure" face is under consideration, and the pitch angle is determined by the points K and J, as illustrated by Figure 2. If the blade varies from the designed "contour," the gage will be above the computed values of the points K and J. Therefore, it is necessary to cut into the blade surface the proper "contour" and this procedure is checked with the gage until the points K and J are accurately located. By this means, a "contour" of the face has been correctly established. The process continues for all gages of a face and afterwards the metal between the section "contours" is chipped off and a careully faired surface results. The blade is finished by grinding and polishing.

The formula established to determine the proper form of fillet where the blade joins the hub has required some study to develop a method for accurately conforming to this requirement for the pattern and for checking the casting and finished surface.

The principles of Descriptive Geometry are utilized for this purpose. Planes normal to the propeller shaft axis are passed through the blades and the intersections determined. The form of the fillet is laid out, in accordance with formula, at right angles to the propeller face, as required by the designs, and then projected on these normal planes. The "contour" for each radial gage is established by this method, as illustrated by Figure 3. The typical form in which the gage data is issued to the shops is illustrated by Figure 4.


A
B
C
D
E
RADIAL GAGES ARE PROVIDED FOR THE DRIVING AND THE SUCTION FACES IN EACH OF THE PLANES A,B,C,D & E NORMAL TO THE PROPELLER SHAFT AXIS.
PROPELLER SHAFT AXIS
SECTION "B-B"
FILLET GAGE (OFFSETS ARE FURNISHED SHOPS TO ESTABLISH THE CONTOURS.)
CONTOUR

FILLET GAGE

FIGURE 3

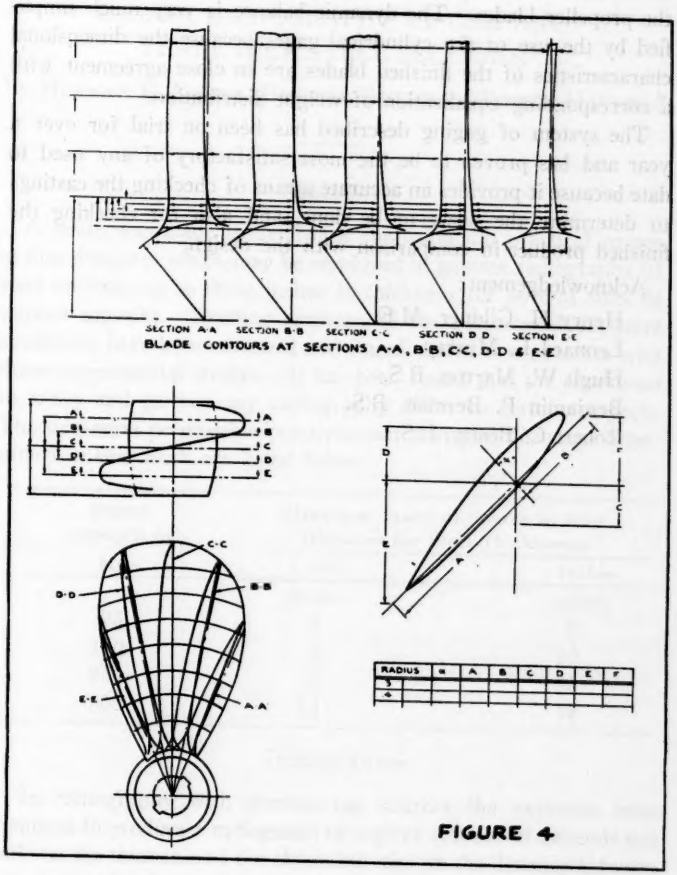

SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
BLADE CONTOURS AT SECTIONS A-A, B-B, C-C, D-D & E-E
A1
B1
C1
D1
E1
A
B
C
D
E
C-C
D-D
B-B
E-E
A-A
RADIUS
A
B
C
D
E
F
3
4

FIGURE 4

The making of the patterns, which is the beginning of the manufacturing operation, is very carefully and accurately done. The foundry procedure is carefully performed with the result that there is relatively little excess metal to be removed from the propeller blades. The dynamic balance is very much simplified by the use of the cylindrical gages because the dimensional characteristics of the finished blades are in close agreement with a corresponding equalization of weight distribution.

The system of gaging described has been on trial for over a year and has proven to be the most satisfactory of any used to date because it provides an accurate means of checking the castings to determine the work to be done, and also for checking the finished product in comparison with the design.

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MINIMUM DISTANCE REQUIREMENTS IN THE GAMMA RADIOGRAPHY OF ONE AND THREE INCH STEEL SECTIONS.

By HERMAN F. KAISER, HERBERT FRIEDMAN, ROBERT HAFNER.*

ABSTRACT.

A study was made to determine the minimum practical source to film distances which may be employed in gamma radiography of steel sections up to three inches in thickness for several sizes of radium capsules. Existing analyses of the geometrical exposure conditions have been reviewed and found useful in connection with these experimental studies. It has been found that the conditions in x-ray and gamma ray radiography differ in certain respects. The minimum permissible practical source to film distances determined in this work are listed below:

Source Strength in Mg.	Minimum Practical Source to Film Distances for Steel Thicknesses	
	1 inch	3 inches
	inches	inches
25	6	9
100	8	10
250	10	12
500	14	16

INTRODUCTION.

In radiography with gamma ray sources the exposure time required to produce a radiograph of a given test object depends not only on the thickness of the object but also on the distance between the source of radiation and the film. Obviously the closer the source is placed to the film the less the exposure time required, and it is in the interest of time saved as well as the rental or investment cost of

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the radium source to use it as near the film as possible. It is known, however, that when the distances used are too short, loss of detail and defect visibility results. An investigation was made to determine how close various sized radium sources may be used. It is already known that these distances are mainly determined by the geometrical relationships between the sizes of source and defect, the thickness of the test object and the distance between the radium source and the defect as illustrated in Figure 2. However, there are other factors involved which are not so easily evaluated, so that it was considered best to supplement existing work in this field with direct experimental work.

To some extent it is possible to derive information which is helpful and pertinent to this problem from experimental work in the field of x-ray radiography, although it must be kept in mind that the conditions in the two fields are not *parallel*. Also useful in this connection will be various theoretical attempts to define the conditions in radiography which must be met to secure optimum results. These attempts have in the past been based mainly on purely geometrical conditions and have not included the evaluation of the effects of the physical processes of absorption and scattering of the radiation. A complete and rigorous theoretical treatment of this subject is still lacking. What pertinent experimental and theoretical material is available will be discussed below.

In gamma radiography, a rough rule determined from general experience stated that the radium source should be used at a distance of 18 inches or more from the radiographic film to secure necessary radiographic *sensitivity*. This rule has become the subject of much comment because rigid adherence to it makes radiography impracticable under some conditions, and also since it allows no shortening of the exposure time by moving the radium source closer to the work. It must be said too, that this arbitrary rule does not consider the size of the radium source itself, which is obviously a factor in determining the definition realizable. In addition to the size of the source there is also the matter of the size of defects or depth sensitivity to be considered. It must be kept in mind from the outset that the least distance at which a source of given size may be used depends on the size of defects that the operator expects to reveal. If the defects are of a coarse nature, it is in the interest of economy to employ shorter working distances. This is a matter on

Table I

Effects on definition of varying sizes of focal area and various d/t ratios

Circular Focal Spot 20 mm in Dia.					Circular Focal Spot 11 mm in Dia.					Elliptical Focal Spot 11mm x 4.5mm				
Film No.	d in "	t in "	d/t	Character of Image	Film No.	d in "	t in "	d/t	Character of Image	Film No.	d in "	t in "	d/t	Character of Image
					39	15	4	3.8	Very diffuse					
					38	15	2	7.5	" "					
50-4	50	4	12.5	Diffuse	32	40	4	10.0	Diffuse	98	15	2	7.5	Diffuse
					28	40	3	13.3	Slightly diffused					
60-4	60	4	15.0	Diffuse	35	15	1	15.0	" "	105	35	3	11.7	Fairly sharp
					71	70	4	17.5	Fairly sharp					
60-3	60	3	20.0	Sharp	67	80	4	20.0	Sharp	106	45	3	15.0	Sharp
					69	90	4	23.0	Very sharp	99	20	1	20.0	Very sharp
50-2	50	2	25.0	Sharp	66	80	3	27.5	" "	107	45	2	23.0	" "
50-1	50	1	50.0	Very sharp	95	30	1	30.0	" "	103	30	1	30.0	" "

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which no hard and fast specifications can be drawn, and it was the primary purpose of this work to determine the minimum distances at which radium sources of several definite sizes can be used to obtain maximum possible definition and sensitivity.

The same problem may be found in x-ray work where it is necessary to evaluate the effect of the size of the focal spot of the x-ray tube on the definition and sensitivity of the radiograph. This has been studied in an experimental way by H. H. Lester (1) whose results are given in a Watertown Arsenal Report, "Some Aspects of Radiographic Sensitivity in X-ray Testing." Table I taken from this report shows the results obtained using x-ray tubes having three different size focal spots and operated at various distances (d) (from film) on several metal thicknesses (t). For each combination of operating distance and metal thickness the ratio d/t is correlated with the character of the image observed. Inspection of Table I shows for all the focal spot sizes, that no sharp image of the defect (in this case a standard crack) is obtained until a d/t ratio of 11.7 is reached. This value is the least observed with the smallest focal spot. For the largest focal spot the required ratio has risen to 20.0. The table indicates at least a rough correlation of d/t ratio to focal spot size. If we take the elliptical focal spot listed as equivalent to a 7 m m circular spot and divide in each of the three cases the d/t ratio for very sharp definition by the size of the focal spot, we get the three ratios $\frac{50}{20}$, $\frac{23}{11}$, and $\frac{20}{7}$ or 2.5, 2.1 and 2.8, which indicates that the quantity $\frac{d}{t\phi}$ where ϕ = size of focal spot, is one that determines largely the quality of the x-ray image.

These findings of H. H. Lester have found experimental verification abroad. In Figure 4 (a) are shown some curves determined by R. Berthold (2) in which the quality of the radiograph expressed in arbitrary units is plotted against the merit figure $\frac{d}{t\phi}$ expressed in reciprocal m m just as in the preceding paragraph. It will be noted that here also the maximum definition is not reached

until the value of $\frac{d}{t\phi}$ is about 2. Above this value no appreciable improvement takes place, but below it the quality of the radiograph falls off rapidly. (It will be shown further on below that the quantity $\frac{d}{t\phi}$ has a physical significance and that it is very obviously related to radiographic definition.)

On the basis of these results and an assumed analogy between focal spot size and radium capsule size we might say at once that since the average radium capsule is certainly less in any cross-sectional area than an 11×4.5 m m focal spot area that any gamma radiographic set-up in which the d/t ratio was 12 or greater would give good definition, or going further and more precisely, any set-up in which the ratio $\frac{d}{t\phi} = 1.5\left(\frac{1}{m\,m}\right)$ would give satisfactory definition. For a radium source of average diameter 4 m m this would mean $\frac{d}{t} = 6$ or about 18 inches working distance for a 3-inch section. While this seems to be in good accord with the rough empirical rule mentioned earlier, it will be seen that matters are somewhat more complicated than is supposed, and we cannot directly adopt some value of d/ϕ to apply to all gamma radiography. For the sake of later comparison, Table 3a gives the minimum d/t ratios computed from the above rule $\left(\frac{d}{+\phi} = 1.5\right)$ for each of the several sizes of radium capsules (Figure 1).

Next to be discussed is a geometrical theory of image formation in radiography due to G. E. Doan which fortunately he has tried to verify by some experimental gamma radiography, using small radon sources. Figure 2 shows the geometrical relationships that will exist between a radium source, a flaw of spherical shape in a test sample and the image of this defect in the photographic plate. The figure shows that the whole image of a defect (cavity) on the radiograph will consist of a central dark portion called the umbra in which the radiation passing through the defect is most intense,

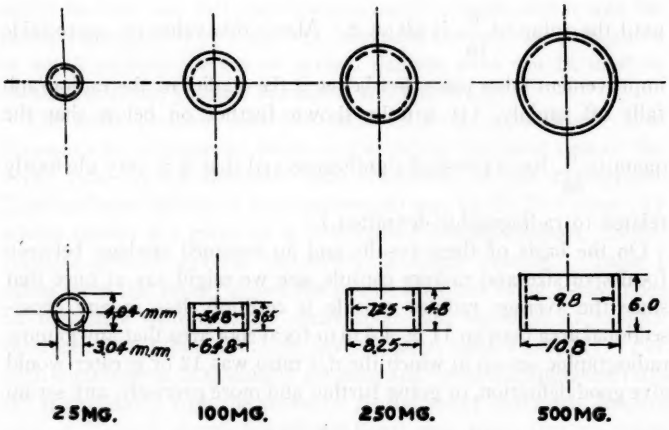

FIGURE 1.—SIZES OF TYPICAL CAPSULES.

Table 2

Typical Sizes of Radium Capsules

Approximate Strength Mg	No. in Use	Outside Height mm	Outside Diameter mm	Inside* Diameter mm
25	1	(Spherical)	4.04	3.04
100	4	3.65	6.48	5.48
170	3	4.50	7.70	6.70
200	2	4.40	7.80	6.80
250	8	4.80	8.25	7.25
275	1	5.10	9.00	8.00
300	2	5.16	9.10	8.10
410	1	5.19	9.73	8.73
500	2	6.00	10.80	9.80

*These diameters are taken as the source diameters "Ø" or "2R" for all discussion in this report.

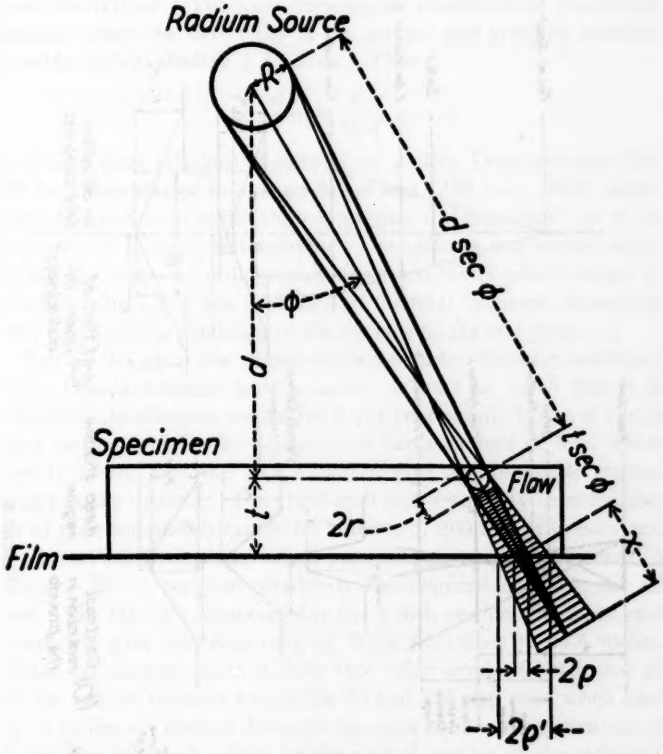

FIGURE 2.

plus a half-dark zone or penumbra in which the radiation is weaker because it came from only a part of the source. From this simple geometrical picture it might be possible to calculate exactly the minimum distance which may be used between source and object or film. This may be expressed by the formula

$$\frac{(R-r)}{(r-q'\cos\phi)}.t$$

in which R is the radius of the source, r the radius of the defect, q' the radius of the image, d and t the distances between source and defect and between defect and film respectively, and ϕ the angle

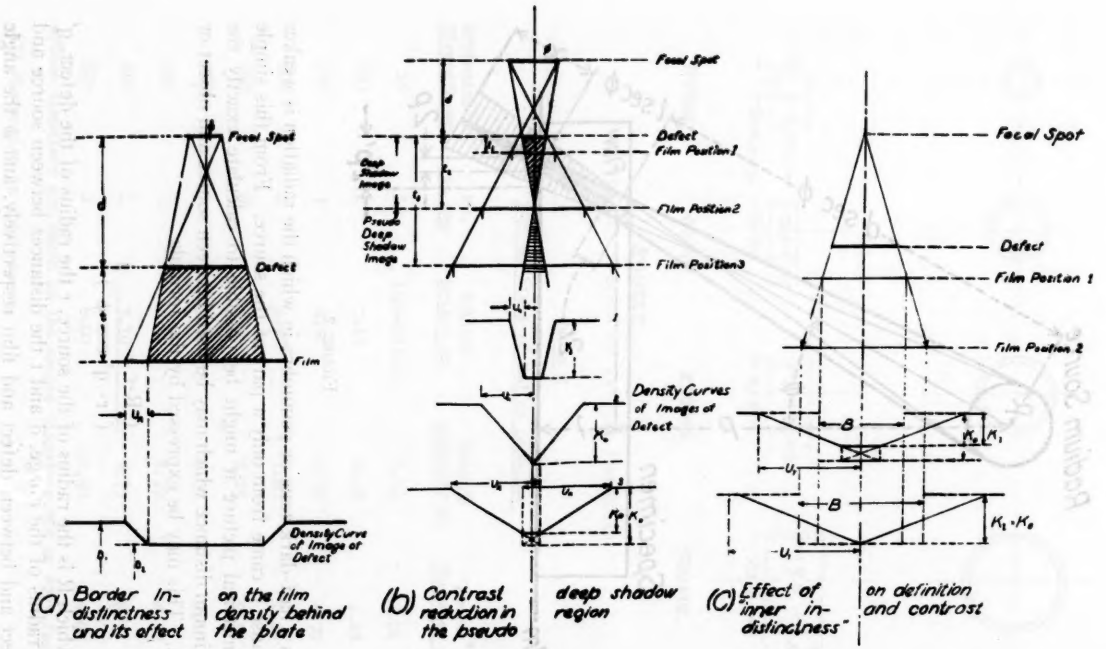
Focal Spot
Defect
Film
Density Curve of Image of Defect
(a) Border indistinctness and its effect on the film density behind the plate
Deep Shadow Image
Pseudo Deep Shadow Image
Film Position1
Film Position2
Film Position3
Density Curves of Images of Defect
(b) Contrast reduction in the pseudo deep shadow region
Film Position 1
Film Position 2
(c) Effect of "inner indistinctness" on definition and contrast

FIGURE 3.

from the vertical. The most unfavorable conditions of course are those in which the defect lies in the surface and gives its smallest possible umbral shadow ($\phi = o$). Then

$$\frac{d}{t} = \frac{R\text{-}r}{r\text{-}q'}$$

In testing these relations in gamma ray studies, Doan assumed that the least diameter of the image-defect was 1/32 inch, which seems quite fair and even optimistic considering the graininess apt to be encountered in many radiographs. The radius r was chosen equal to half the supposed radiographic depth sensitivity which ranges in practice from 1.5 to 4 or 5 per cent of the total thickness, depending very much on the condition of the surface of the test piece.

Table 3(b) gives the values of the minimum distance calculated from Doan's formula with $\phi = o$. It may be noted that it is impossible to compute values for 2 per cent sensitivity on a 1-inch steel section because the denominator becomes zero or less, which merely means that the source cannot give an observable umbral image at any distance. For the 3-inch sections it may be noted that all of the computed distances for sources of 100 mg. or greater and 2 per cent sensitivity have values just under or over the arbitrary 18 inches. For 4 per cent sensitivity the required distances are all less. The distance computed for the 1-inch section and 4 per cent sensitivity give distances ranging from 7.9 inches to 34.6 inches. These calculations taken at their face value would indicate that all of the radium capsules except the 25 and 100 mg. sizes when used at 18 inches are used at distances too close to obtain registration of 2 per cent spherical defects by the central portion of the radiation. What registration is obtained must be due to the penumbral part of the image which, from a study of Figure 2, will always be present and becomes greater the closer the source is placed to the defect. It is not strictly possible to speak of a "minimum distance" for penumbral registration because as just said, this occurs at any close distance, but we can compute a distance at which the penumbral image has some minimum size that we feel sure can be recognized. Remembering that any penumbral image is a hazy one at best, we can put the minimum image diameter at 1/8 inch and compute d from Doan's formula for the penumbral image:

$$d = \frac{R + r}{q' - r}.t$$

Table 3 (a)

Minimum Distances Determined from the Rule $d/t^{\phi} \geq 1.5$

Source mg	d/t	"d" for Steel Thickness "t" 1"	3"	6"
25	4.56	4.5 (in.)	13.7	27.4
100	8.22	8.2	24.7	49.4
250	10.98	11.0	33.0	66.0
500	14.70	14.7	44.1	88.0

Four source to film distance add "d" to "t".

Table 3 (b)

Minimum Distances Required for Umbral Registration of Small Defects as Computed from Doan Formula

Source mg	Diameter (2R)(in)	Defect:	"d" for Steel Thickness "t" 1" 2%	1" 4%	3" 2%	3" 4%
25	0.119		—	7.9"	5.9"	(any dist.)
100	0.217		—	17.7"	15.5"	3.25"
250	0.285		—	24.5"	22.5"	5.5"
500	0.386		—	34.6"	32.5"	8.9"

Table 3 (c)

Minimum Distances at which Radium Sources of Various Sizes May Be Used to Obtain Penumbral Registration of 2% Defects

$\rho' = 1/16$ in. (.0625") (Doan equation) $d = \frac{R + r}{\rho' - r} \cdot t$

Source mg	Radius R (in)	"d" (Source to defect distance for Steel Thickness) 1"	3"
25	0.059	1.31	8.22
100	0.108	2.24	12.72
250	0.143	2.91	15.96
500	0.193	3.86	20.58

For source to film distances add section thickness to "d".

Table 3(c) gives the results of calculations made from this formula for several typical source sizes used in radiography. This table would indicate that if we could be content with penumbral registration of defects very short source to film distances may be employed.

To test the formulae given, Doan used two radon sources having diameters of about 1/10 and 1/4 inch which correspond closely to

the 25 and 100 mg. radium sources of this study. He used steel blocks having in their sides facing the source artificial defects consisting of holes and slots bored or milled to various depths corresponding to various percentages of the total block thickness. The image diameters were carefully measured and then compared to the theoretical diameter given by the formulae for the umbral and penumbral diameters. In all cases the observed diameters were between the computed umbral and penumbral diameters. The failure to observe the computed penumbral diameter is attributed to the very diffuse nature of the penumbra making its exact experimental determination impossible.

In summarizing the experimental part of the work it is reported that the general condition for the formation of sharp images (no penumbral haze) is that the source and defect subtend a common vortex angle of about 2 degrees. Registration however continues to take place more and more poorly until this angle is about 10 degrees. Beyond this registration may fail completely.

Before concluding the discussion of other work dealing with this problem, it will be well to mention work similar to Doan's carried out by Berthold (2) in the x-ray field. Here again the considerations are mainly of a geometrical nature but the writer goes a step further and takes into consideration also the photographic contrast relationships that enter into image formation under various conditions.

The factor that is of main importance in registration of a defect is the contrast which in the work discussed is taken as the *difference in density* between a point in the image and any point outside of the image. Even if the edges of the defect image are blurred, the defect can still be seen provided the contrast is high enough. Blurring on the edges or what may be called lack of definition arises from two or more causes and may even seriously affect the contrast when certain geometrical conditions exist. The primary factor controlling lack of definition is a geometrical indistinctness due to the penumbral haze mentioned. This indistinctness can be simply represented as the width of the penumbral shadow and is expressed as

$$U_r = \frac{t}{d\phi}$$

which we recognize as the reciprocal of the "figure of merit". Its derivation is evident from Figure 3(a) which also shows at

the bottom the schematic course of density through the defect image. For the sake of clarity the course of the density is shown to be linear; actually there is a rounding off of the density at both ends of the curve in the penumbral range. More will be said about this later.

In Figure 3(b) are shown three more schematic density curves below a sketch of geometrical conditions similar to that shown in Figure 2. These curves correspond to the three cases: (a) where the radiographic film includes the umbral shadow of the image, (b) where the film just meets the apex of the umbral cone, and (c) where the film is entirely within the penumbral range. It is easy to see that in the first two cases the maximum contrast is maintained at the center of the image, but that in the third case there is a decrease in contrast. Simple geometry shows that the limiting conditions of case (b) at which no loss of contrast occurs are simply:

$$\frac{t\phi}{d} = \frac{r\,\phi}{\phi - r} = U_r$$

Solving: $$d = \frac{\phi - r}{r}.t$$

a formula which is very similar to Doan's, the difference lying in the fact that here the size of the umbral image is not finite but zero.

It has been shown above that a diminution of contrast and therefore a loss in radiographic sensitivity occurs when certain geometrical conditions are exceeded. Berthold in his work points out still another factor that will operate to bring about a reduction in contrast. This he calls the "inner" indistinctness U_i to distinguish it from the geometrical indistinctness U_r. It is almost entirely due to the radiographic film and the intensifying screen. It can easily be shown by photometering the image of a sharp edge in a radiograph that the density does not change abruptly as demanded by geometry, but has a decided range over which it falls. This is due to several things, among them the scattering of photoelectric and Compton electrons in the emulsion, the scattering and spreading of the fluorescent light and secondary x-rays generated by the intensifying screens and last but not least, at times by the scattering of radiation by matter near the edge of the test piece adjacent to the film (a familiar effect known as "halation" or

"undercutting"). For simplicity again, Berthold assumes that the course of the density change across the geometrical edge is linear and in addition symmetrical (as much density change on one side as on the other).

In Figure 3(c) is shown schematically the operation of this factor for two positions of a radiographic film, for a finite defect and point source. It may be noted in this figure that when the film is close to the defect a decrease in contrast will occur just as in the geometrical case of Figure 3(b), but that when the film is removed to a certain minimum distance this does not happen. In this case the geometrical condition which defines U_i is: $U_i = r\left(\frac{d+t}{t}\right) = r\,v$ where v is magnification of the defect edge in the radiograph.

Berthold has considered the overlapping action of these two contrast diminishing effects and has found that where either of the two values U_r and U_i is 30 per cent less than the other one, only the larger one has any effect on the quality of the radiograph. Furthermore, it has been found experimentally that the linear portion of the density curve is only about 70 per cent of the total when the rounded ends are subtracted. This simplifies matters so that we may say that the maximum radiographic quality is obtained when the geometrical indistinctness U_r is equal to the film indistinctness U_i (a fixed quantity). In general U_i has a value of several tenths of a m m in x-ray work, (Berthold cites a case of 0.7 m m for x-rays with 1 m m Cu half value), while U_r can be made very much smaller. It was shown in Figure 3(c) that the bad effect of U_i on the contrast could be decreased and removed by increasing the distance t or the magnification v of the defect. From the condition that $U_r = U_i$ we get for the equation defining the best possible geometrical condition for obtaining radiographs of the highest quality

$$U_r = \frac{t\,\phi}{d} = U_i = r.\ v.$$

Since U_i is a constant of the film and screens, this equation leads to a pair of curves giving v as a function of r and ϕ as a function of r, the defect size. Figure 4(b) shows these curves and shows that for any size defect to be revealed there is an optimum $v = \left(1 + \frac{t}{d}\right)$ and an optimum focal spot size.

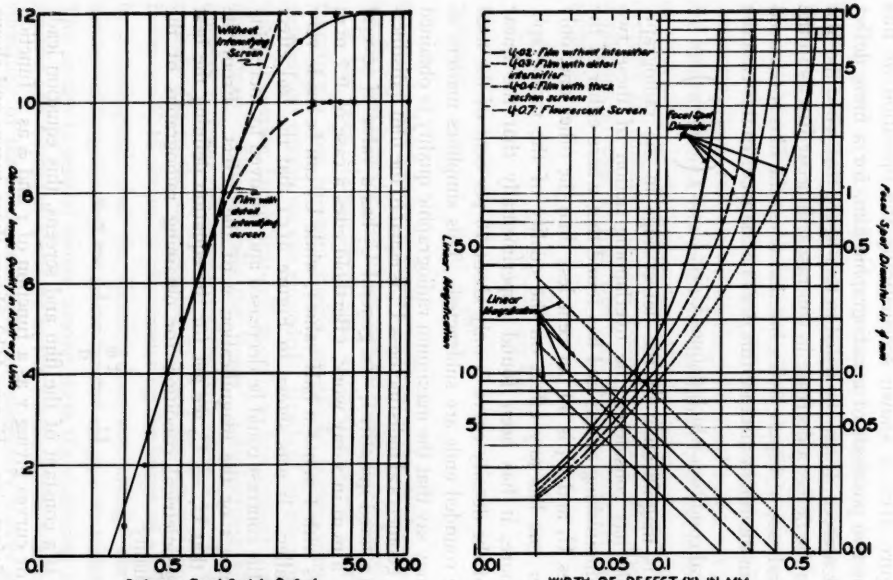
12
10
8
6
4
2
0.1
0.5
1.0
5.0
100
Without intensifying Screen
Film with detail intensifying screen
Observed Image Quality in Arbitrary Units
Distance: Focal Spot to Defect / (Distance of Defect to Film) x Focal Spot Diameter = 1/mm
Effect of Definition on X-ray Radiographs.
(a)
—402: Film without intensifier
—403: Film with detail intensifier
—404: Film with thick section screens
—407: Fluorescent Screen
Focal Spot Diameter
Linear Magnification
50
10
5
1
0.001
0.05
0.1
0.5
WIDTH OF DEFECT (x) IN MM
Focal Spot Diameter in f mm
10
5
1
0.5
0.1
0.05
0.01
Geometric exposure conditions for production of X-ray pictures of maximum quality.
(b)

FIGURE 4.

While Berthold's considerations have been built up from x-ray experience, it is not too much to expect that considerations of this kind will be of equal value to gamma radiography. The valuable contribution of Berthold consists in bringing into consideration the non-geometrical factor, film indistinctness.

In the work of both Doan and Berthold nothing is said about the possible effect of scattered and secondary radiation on the quality of the radiograph. It might be said that the effect of the secondary radiation is to produce a general fog veiling the whole radiograph more or less uniformly and thus not interfering with details of the radiograph. Nevertheless, it cannot be denied that it has a bad effect on the quality of the radiograph because the intensity of the secondary radiation is at least several times greater than the direct radiation producing the image. Lester (1) believes that this leads to under-exposure of the radiograph as far as the defect image is concerned. In gamma radiography only a few per cent of the absorbed radiation is truly absorbed. The major portion is "absorbed" by simple and Compton scattering. Seeman (4) has undertaken an analysis of the geometrical conditions relating to the scattering of x-rays for a few somewhat idealized cases, and has indicated the importance of this factor in radiography, but a complete mathematical treatment of scattering of gamma radiation in large extended masses has not, as far as is known, been attempted.

While Tables 3(a) and 3(b) contain certain values of working distances that might be applied in the use of radium capsules in the radiography of steel sections of various thickness, it is not certain since these are based mainly on the geometrical consideration outlined above that they will represent the best working distances to be used. The subject was therefore explained especially and the results obtained will be compared to the above considerations further on.

Experimental.

The method followed in the experimental determination of minimum distance was as follows: Steel test blocks were prepared in which small defects in the form of small holes of various diameters and depths were present in one face of the block as shown in Figure 5. These test blocks of one and three inch thick-

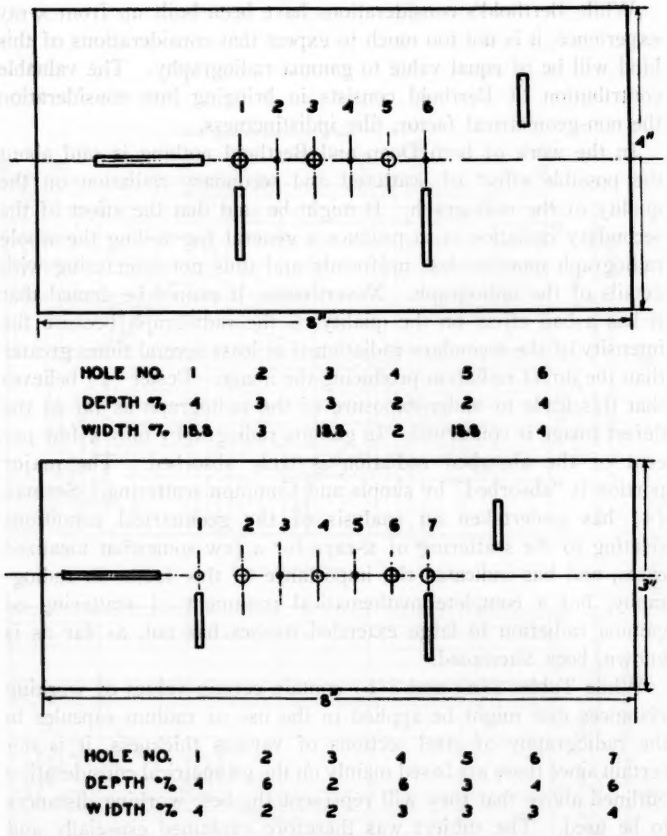

FIGURE 5.

ness were radiographed at a number of source to film distances using radium sources of sizes representative of those in Figure 1, that is, 25, 100, 250 and 500 mg. sources. Exposures were of sufficient duration to give densities around one using the standard technique with 2 films between three lead foils of about 0.006-inch thickness. The films were processed by standard gamma-ray development technique.

Table 4 (a)

Test Exposures Made on 1" Steel Test Block

Source to Film Distance	Exposure Time in Hours with Sources: 25	100	250	500 (mg)
4"	0.6	0.15	0.065	0.032
8"	2.4	0.63	0.255	0.127
12"	5.4	1.45	0.580	0.29
16"	10.0	2.50	1.00	0.50
20"	17.0	4.05	1.62	0.81
24"	23.2	5.8	2.33	1.16
28"	31.2	7.8	3.15	1.57

Table 4 (b)

Test Exposures Made on 3" Steel Test Block

Source to Film Distance	Exposure Time in Hours with Sources: 25	100	250	500 (mg)
4"	3.0	0.75	0.30	0.15
8"	12.0	3.00	1.50	0.75
12"	27.0	6.75	2.70	1.35
16"	48.0	11.75	4.70	2.35
20"	74.0	18.5	7.40	3.7
24"	—	26.5	10.6	5.3
28"	—	—	14.4	7.2
32"	—	—	19.0	9.5
36"	—	—	24.0	12.0
40"	—	—	—	15.0
44"	—	—	—	17.5

Table 5 (a)

Figures of Merit* for Defect Visibility in Each Pair of Test Films. Source: 25 mg. Section 1".

Test Run No.	Film Pr. Nos.	Dist. In.	Merit Figs. for Visibility No. 1	2	3	4	5	6	All	d / t	d (1) / t√(mm)
21	1, 2	4	6	2	3	0	0	0	11	3.0	1.0
21	3, 4	8	5	0	4	0	2	0	11	7.0	2.3
22	5, 6	12	4	0	4	0	4	0	12	11.0	4.3
26A	7, 8	16	4	0	2	0	2	0	8	15.0	4.95
24	9, 10	20	4	0	4	0	3	0	11	19.0	6.24
21	11, 12	24	4	0	4	0	2	0	10	23.0	7.56
29	13, 14	28	4	0	3	0	2	0	9	27.0	8.90
	Defect: % Width		19	3	19	2	19	4			
	% Depth		4	3	3	2	2	4			

Table 5 (b)

Figures of Merit for Defect Visibility in Each Pair of Test Films. Source: 25 mg. Section 3".

Test Run No.	Film Pr. Nos.	Dist. In.	Merit Figures for Visibility No. 1	2	3	4	5	6	7	All	d / t	d(1) / t√(mm)
21	15, 16	4	0	0	0	0	0	0	0	0	1.33	0.43
26	17, 18	8	4	1	0	3	3	1	4	16	2.66	0.88
26	19, 20	12	5	4	1	4	2	3	5	24	4.00	1.32
24	21, 22	16	6	3	0	1	3	2	6	21	5.33	1.75
22	23, 24	20	6	2	0	3	2	3	6	22	6.66	2.19
	Defect: % Width		4	6	2	6	3	4	6			
	% Depth		4	2	2	3	3	3	4			

*Merit Figures:

0 = defect invisible.

1 = fairly visible.

2 = visible.

3 = sharp.

Figures are summed for each pair of films.

Table 6 (a)

Figures of Merit for Defect Visibility in Each Pair of Test Films. Source 100 mg. Section 1".

Test Run No.	Film Pr. Nos.	Dist. In.	Merit Figures for Visibility No. 1	2	3	4	5	6	All	d t	d (1) tØ(mm)
19	3, 4	4	4	0	4	0	4	0	12	3	0.55
19	1, 2	8	6	0	4	0	2	0	12	7	1.28
16	1, 2	12	6	0	6	0	5	1	18	11	2.01
14	1, 2	16	4	0	3	0	0	0	7	15	2.73
18	1, 2	20	6	0	6	0	3	0	15	19	3.47
17	1, 2	24	6	0	5	0	3	1	15	23	4.20
15	1, 2	28	6	0	6	0	0	6	18	27	4.93
	Defect: % Width		19	3	19	2	19	4			
	% Depth		4	3	3	2	2	4			

Table 6 (b)

Figures of Merit for Defect Visibility in Each Pair of Test Films. Source 100 mg. Section 3".

Test Run No.	Film Pr. Nos.	Dist. In.	Merit Figures for Visibility No. 1	2	3	4	5	6	7	All	d t	d (1) tØ(mm)
16	3, 4	4	0	0	0	0	0	0	0	0	1.33	0.24
	5, 0	4	0	0	0	0	0	0	0	0	1.33	0.24
14	3, 4	8	4	1	1	3	3	3	5	20	2.66	0.48
	5, 6	8	4	2	0	3	0	3	4	16	2.66	0.48
15	3, 4	12	6	6	2	5	6	6	5	36	4.0	0.72
	5, 6	12	6	6	1	6	6	4	6	35	4.0	0.72
12	3, 4	16	6	6	3	6	4	6	6	37	5.33	0.96
	5, 6	16	6	5	1	6	5	5	6	34	5.33	0.96
4	1, 2	18	6	4	1	6	4	4	6	31	6.0	1.09
	3, 4	18	3	3	0	4	3	4	4	21	6.0	1.09
13	1, 2	24	6	5	4	6	4	4	6	35	8.0	1.44
	3, 4	24	4	4	1	5	4	4	6	28	8.0	1.44
	Defect: % Width		4	6	2	6	3	4	6			
	% Depth		4	2	2	3	3	3	4			

Table 7 (a)

Figures of Merit for Defect Visibility in Each Pair of Test Films. Source 250 mg. Section 1".

Test Run No.	Film Pr. Nos.	Dist. In.	Merit Figures for Visibility No. 1	2	3	4	5	6	All	d / t	d (1) / tø (mm)
11	5, 6	4	3	0	2	0	1	0	6	3	0.41
	3, 4	8	4	0	4	0	3	0	11	7	0.97
	1, 2	12	6	0	5	0	5	0	16	11	1.52
9	1, 2	16	6	0	4	0	3	2	15	15	2.07
8	1, 2	20	6	0	4	0	4	1	15	19	2.62
6	1, 2	24	3	0	6	0	6	0	15	23	3.17
3	1, 2	28	0	0	3	0	3	0	6	27	3.72
Defect:		% Width	19	3	19	2	19	4			
		% Depth	4	3	3	2	2	4			

Table 7 (b)

Figures of Merit for Defect Visibility in Each Pair of Films. Source 250 mg. Section 3".

Test Run No.	Film Pr. Nos.	Dist. In.	Merit Figures for Visibility No. 1	2	3	4	5	6	7	All	d / t	d (1) / tø (mm)
9	3, 4	4	0	0	0	0	0	0	0	0	1.33	0.183
	5, 6	4	0	0	0	0	0	0	0	0	1.33	0.183
8	3, 4	8	2	0	0	3	2	2	5	14	2.66	0.366
	5, 6	8	2	0	0	3	3	3	4	15	2.66	0.366
6	3, 4	12	4	4	1	4	4	4	4	25	4.0	0.549
	5, 6	12	5	4	2	5	4	4	6	30	4.0	0.549
3	3, 4	16	5	2	0	5	4	4	5	25	5.33	0.732
	5, 6	16	3	1	0	4	4	4	4	20	5.33	0.732
10	1, 2	20	6	4	1	6	4	4	6	31	6.66	0.915
	3, 4	20	6	4	4	6	5	4	6	35	6.66	0.915
7	1, 2	24	6	6	3	6	6	6	6	39	8.0	1.098
	3, 4	24	6	5	1	6	5	6	6	35	8.0	1.098
5	1, 2	28	6	5	1	6	4	5	6	33	9.33	1.281
	3, 4	28	6	4	0	5	4	4	6	29	9.33	1.281
Defect:		% Width	4	6	2	6	3	4	6			
		% Depth	4	2	2	3	3	3	4			

Table 8 (a)

Figures of Merit for Defect Visibility in Each Pair of Test Films. Source 500 mg. Section 1".

Test Run No.	Film Pr. Nos.	Dist. In.	Merit Figures for Visibility No. 1	2	3	4	5	6	All	d t	d(1) ψ(mm)
27	25, 26	4	3	0	2	0	0	0	5	3	.307
27	27, 28	8	4	0	3	0	2	0	9	7	.714
27	29, 30	12	4	0	4	0	2	1	11	11	1.12
27	31, 32	16	6	0	4	0	2	0	12	15	1.53
27	33, 34	20	4	0	2	0	2	0	8	19	1.94
27	35, 36	24	4	1	3	0	3	2	13	23	2.35
25	37, 38	28	4	0	3	0	3	0	10	27	2.75
	Defect:	% Width	19	3	19	2	19	4			
		% Depth	4	3	3	2	2	4			

Table 8 (b)

Figures of Merit for Defect Visibility in Each Pair of Test Film. Source 500 mg. Section 3".

Test Run No.	Film Pr. Nos.	Dist. In.	Merit Figures for Visibility No. 1	2	3	4	5	6	7	All	d t	d (1) ψ(mm)
25b	40, 41	4	0	0	0	0	0	0	0	0	1.33	.136
28	42, 43	8	2	0	0	3	0	1	3	9	2.66	.272
28	44, 45	12	3	2	0	3	1	0	4	13	4.0	.408
25b	46, 47	12	3	2	0	3	2	3	3	17	4.0	.408
25	48, 49	16	4	3	0	4	4	4	4	23	5.33	.544
25	50, 51	20	3	3	1	4	4	4	4	23	6.66	.680
23	52, 53	24	3	2	0	3	3	3	4	18	8.00	.816
27	54, 55	28	2	2	0	1	2	2	3	12	9.33	.952
27	56, 57	32	3	2	0	3	1	2	3	14	10.66	1.09
25	58, 59	36	3	3	0	3	1	1	3	14	12.00	1.22
28	60, 61	40	3	3	0	3	3	*	4	19	13.33	1.36
29	62, 63	40	4	3	1	3	2	*	3	19	13.33	1.36
25	64, 65	44	4	2	0	4	2	2	4	18	14.66	1.49
	Defect:	% Width	4	6	2	6	3	4	6			
		% Depth	4	2	2	3	3	3	4			

*Hole absent in extra 3" test block used.

The radiographs obtained were viewed on an illuminator and the number of defects visible and their nature were recorded. The tables of data obtained are too lengthy to warrant reproduction in this paper but these tables have been condensed into Tables 5-8 by assigning merit figures to each defect and summing these for each pair of films. The merit figures for the individual defects are summed and tabulated as a figure of merit for the test exposure as a whole.

The data contained in Tables 5-8 shows what quality of radiographic image may be obtained at any given working distance. In addition, are given the values of the quantity $d/t\phi$ for the geometrical conditions of each test exposure. A detailed discussion of all of this data being somewhat tedious only the general trends will be discussed here.

The data of Table 5 show that defects begin to register in the radiograph at the rather short working distances of 4 inches in the case of the 1-inch steel section and 8 inches in the case of the 3-inch section. As may be expected from theory defects 2 per cent deep and 2 per cent wide did not record at any distance although a 2 per cent depth sensitivity was present. At the shortest working distances the values of d/t are small but due to the small size of this radium source (25 mg.) the values of the index $d/t\phi$ are large to begin with. It is then natural that registry will begin at comparatively short distances and also that the general quality does not increase much with further increase of distance.

Increase of radium capsule size from 25 to 100 mg. does not materially increase the shortest possible distance of registry but it may be noted in Table 6(a) that there is a more gradual improvement of the quality of registry as the working distance is increased. The data for the 100 mg. source used with a three-inch steel section is given in Table 6(b) and in Figure 6. In the latter the defect visibility in arbitrary units for each of the defects listed is plotted in separate curves against the source to film distance used. As may be expected the visibility of the 2 per cent deep, 2 per cent wide defect is smaller than that of the other defects but the maximum visibility is reached at about the same distance for each separate defect. Referring to the Table 6(b) it may be noted that the values of the distance over thickness ratios are not large and do not reach a value of 8 until the distance has been increased

to 24 inches. The value of $d/t\phi$, however, is near unity at 16 inches at which maximum registry is observed.

The curve in Figure 6 which shows the general visibility for all defects, collectively, may be conveniently taken as representative of the data for each combination of radium source size and steel section thickness.

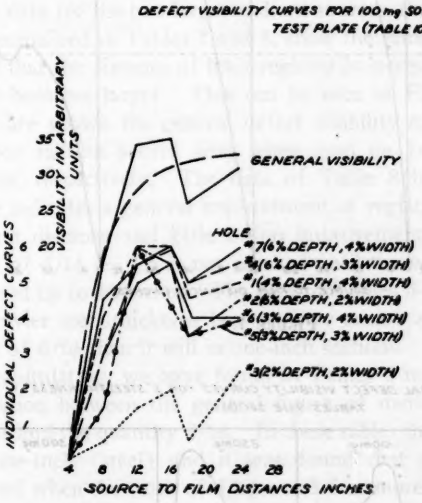
DEFECT VISIBILITY CURVES FOR 100 mg SOURCE AND 3" STEEL TEST PLATE (TABLE 10b)
VISIBILITY IN ARBITRARY UNITS
INDIVIDUAL DEFECT CURVES
GENERAL VISIBILITY
HOLE
#7(6% DEPTH, 4% WIDTH)
#8(6% DEPTH, 3% WIDTH)
#1(4% DEPTH, 4% WIDTH)
#2(3% DEPTH, 2% WIDTH)
#6(3% DEPTH, 4% WIDTH)
#5(3% DEPTH, 3% WIDTH)
#3(2% DEPTH, 2% WIDTH)
SOURCE TO FILM DISTANCES INCHES

FIGURE 6.

A very noticeable feature of the entire set of curves in Figure 6 is the tendency of the curves to form a passing minimum around 18-inch source to film distance. This might be attributed to some unknown variation of the conditions in the test run for this distance, were it not for the fact that this effect is also exhibited if not in such a pronounced way by the data on the 3-inch test plate obtained with 250 and 500 mg. sources. A study of the points in Figure 8 will show this and even the data on the 1-inch test plate shown in Figure 7 show a slight tendency of this kind. It is possible that this effect may be related in some way not yet understood to the secondary scattering in the test block and its environment at various distances. It is not unlikely that as the distance between source

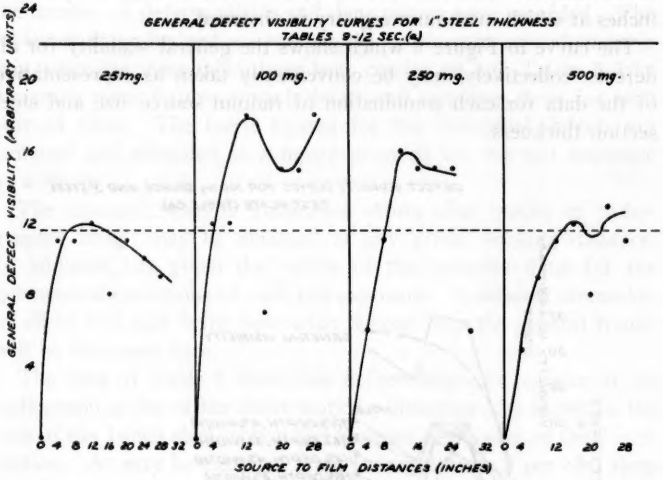

FIGURE 7.

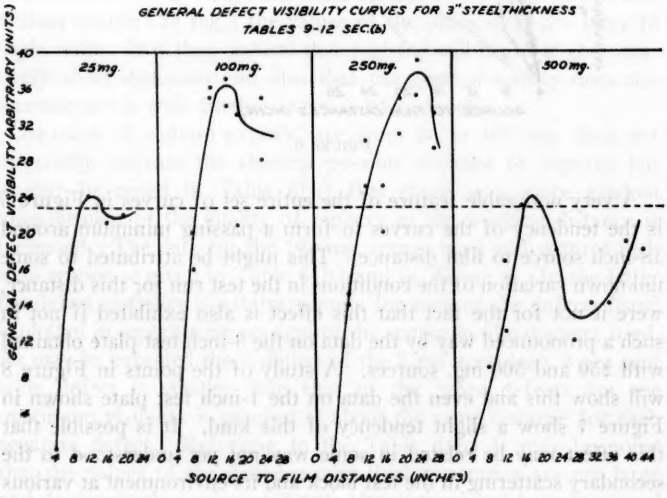

FIGURE 8.

and film is increased the amount of forward scattered radiation in both air and test block is increased and that this factor opposes the increase in definition to be expected on geometrical grounds. It is the purpose of this work to determine by empirical means the best distances to be used in gamma radiography, but supplementary studies to learn more about the scattering processes under various conditions would be worthwhile and are contemplated.

The data for the two larger radium sources, the 250 and 500 mg. sizes, contained in Tables 7 and 8, show the same general behavior except that the distance of least-registry is increased as the radium source becomes larger. This can be seen in Figures 7 and 8 in which are shown the general defect visibility curves for each of the four radium source sizes when used on 1- and 3-inch steel sections, respectively. The data of Table 8(b) for the largest source indicates a general improvement of registry up to 20 inches working distance and little or no improvement beyond although values of $d/t\phi = 1.5$ is not reached until the working distance is increased up to 44 inches. The data of Tables 5-8 indicate that for the heavier steel thickness best registry occurs at somewhat lower values of $d/t\phi$ than it will in one-inch sections.

Recapitulating, we have found in Tables 5 to 8, Section (a), a correlation between the general figure of merit for visibility of defects and the quantity $d/t\phi$. In these tables the section thickness was one-inch (steel) and it was found that good registry was obtained when the value of $d/t\phi$ was 1.5 or more. Likewise, in the tables for the 3-inch section (Tables 5 to 8, Section (b)), it was found the quality of the registry increased with the quantity $d/t\phi$ but seemed to reach its maximum at a point around $d/t\phi = 1$ or even less. It has also been shown that the distances of best registry of most of the defects in the test piece, if they could be recorded at all, were about the same.

In Figures 7 and 8 the general figures of merit for overall registry as given in Tables 5 to 8 have been plotted against their corresponding source to film distances and smoothed curves drawn through these data points. The purpose of these curves is to determine those working distances for each combination of source and section thickness at which best registry was observed to take place and also to determine the least distances at which a satisfactory degree of registry will take place in each case. Since the

Table 9

Apparent Diameters and Image Characteristics of Defect Hole No. 1 in Test Plates

(a) Source 25 mg, Test Plate 1" (5 mm hole).

Distance	Width of Penumbral $\frac{td}{d}$	App. Diam.	True Umbral Diam.	Calc. Diam.	Image Characteristics
4"	1.00	6.0 mm	5.66	8.00	Visible edges fuzzy.
8"	0.43	5.5	5.28	6.14	Visible, well defined.
12"	0.23	5.7	5.18	5.64	Image poorer.
16"	0.20	5.4	5.12	5.52	Visible, but edge not as well defined.
20"	0.16	5.4	5.10	5.42	" " " " "
24"	0.13	5.4	5.08	5.34	" " " " "
28"	0.11	5.3	5.07	5.29	" " " " "

(b) Source 25 mg, Test Plate 3" (3 mm hole).

Distance	Width of Penumbral $\frac{td}{d}$	App. Diam.	True Umbral Diam.	Calc. Diam.	Image Characteristics
4"	2.32	—	—	—	No image visible.
8"	1.14	5.5 mm	3.0 mm	5.28	Visible, very hazy.
12"	0.76	4.3	"	4.52	Fairly visible, edges hazy.
16"	0.57	3.4	"	4.14	" " " "
20"	0.46	3.1	"	3.96	Edges becoming distinct.

(c) Source 100 mg, Test Plate 1" (5 mm hole)

Distance	Width of Penumbral $\frac{td}{d}$	App. Diam.	True Umbral Diam.	Calc. Diam.	Image Characteristics
4"	1.82	6.7 mm	4.83	8.47	Visible, edges indistinct.
8"	0.78	6.3	4.93	6.49	" " "
12"	0.50	6.2	4.96	5.96	" " "
16"	0.37	5.4	4.97-	5.74	" " "
20"	0.29	5.5	4.97+	5.35	More distinct on edges.
24"	0.24	5.0	4.98	5.46	" " " "
28"	0.20	5.3	4.98	5.38	Visible edges still not sharp.

(d) Source 100 mg, Test plate 3" (3 mm hole).

Distance	Width of Penumbral $\frac{td}{d}$	App. Diam.	True Umbral Diam.	Calc. Diam.	Image Characteristics
4"	4.17	—	—	—	No image visible.
8"	2.08	6.9	1.5	5.66	Visible, but badly blurred.
12"	1.39	5.0	2.17	4.95	Visible and more distinct.
16"	1.04	4.5	2.43	4.51	Visible, fairly distinct.
18"	0.92	4.2	2.49	4.33	" " "
24"	0.70	4.1	2.64	4.04	Improving, better than for 16".

Table 9 (Continued)

(e) Source 250 mg, Test Plate 1" (5 mm hole).

Distance	$t\phi$ / d	App. Diam.	True Umbral Diam.	Calc. Diam.	Image Characteristics
4"	2.44	7.4	4.25	9.13	Hazy, indistinct.
8"	1.02	6.5	4.68	6.72	Visible, fairly distinct.
12"	0.66	6.1	4.80	6.12	" " "
16"	0.48	6.1	4.85	5.81	Distinct on double viewing.
20"	0.38	5.7	4.88	5.64	" " " "
24"	0.32	5.5	4.90	5.54	" " " "
28"	0.27	5.6	4.92	5.46	Less distinct edges fuzzy.
72"	0.10	5.3	4.97	5.17	About same as for 16".

(f) Source 250 mg, Test Plate 3" (3 mm hole).

Distance	$t\phi$ / d	App. Diam.	True Umbral Diam.	Calc. Diam.	Image Characteristics
4"	5.46	—	—	—	No image visible.
8"	2.73	6.1	0.45	5.91	Hazy, almost invisible.
12"	1.82	4.8	1.59	5.23	Visible edges very hazy.
16"	1.37	4.0	2.02	4.76	Visible, more distinct.
20"	1.09	3.9	2.25	4.43	" " "
24"	0.91	3.9	2.39	4.21	Visible, fairly distinct.
28"	0.78	3.6	2.49	4.05	" " "
32"	0.75	4.0	2.56	4.05	" " "
36"	0.66	3.8	2.61	3.93	Faint but distinct.

(g) Source 500 mg, Test Plate 1" (5 mm hole).

Distance	$t\phi$ / d	App. Diam.	True Umbral Diam.	Calc. Diam.	Image Characteristics
4"	3.26	9.7	3.40	9.92	Hazy, indistinct.
8"	1.40	6.0	4.31	8.80	Fairly distinct.
12"	0.89	5.5	4.56	6.34	Faint but fairly distinct.
16"	0.65	6.0	4.68	5.98	Visible and quite distinct.
20"	0.52	5.5	4.75	5.79	Visible, fairly distinct.
24"	0.43	5.5	4.79	5.65	Faint, fairly distinct.
28"	0.36	5.5	4.82	5.54	Visible, less distinct.

(h) Source 500 mg, Test Plate 3" (3 mm hole).

Distance	$t\phi$ / d	App. Diam.	True Umbral Diam.	Calc. Diam.	Image Characteristics
4"	7.35	—	—	—	No image visible.
8"	3.68	8.9	—	—	Very hazy.
12"	2.45	6.5	0.74	5.64	Visible edges blurred.
16"	1.84	4.8	1.44	5.12	Improved edges still blurred.
20"	1.47	4.0	1.81	4.75	Visible and fairly distinct.
24"	1.23	4.0	2.02	4.48	" " " "
28"	1.05	3.7	2.18	4.28	Faint but distinct.
32"	0.92	3.3	2.29	4.13	Edges quite distinct.
36"	0.82	3.5	2.38	4.02	Not quite as good as for 32".
40"	0.74	3.2	2.45	3.93	Faint but distinct.
44"	0.67	2.50	3.5	3.84	Good but not better than for 32".

Table 10

Minimum Distances at Which Narrow Slots May be Observed in 1 and 3" Steel Sections, Using a 100 mg Source

(a) Section 1" + 0.25" Slot Plate.

Film No.	Source to Spec. Dist.	Visibility for Slot Widths: 0.001"	0.002"	0.003"	0.004"	0.005"
1	1"	I	I	I	I	I
2	"	I	I	I	I	I
3	3"	I	I	F	V	V
4	"	I	F	V	V	V
5	6"	I	V	V	V	V
6	"	F	V	V	V	V
7	9"	F	F	F	V	V
8	"	F	F	V	V	V
9	18"	V	V	V	V	V
10	"	F	F	V	V	V

Symbols: I (Invisible) F (Faint) V (Visible)

(b) Section 3" + 0.25" Slot Plate

Film No.	Source to Spec. Dist.	Visibility for Slot Widths 0.001	0.002	0.003	0.004	0.005
1	1"	I	I	I	I	I
2	"	I	I	I	I	I
3	3"	I	I	I	I	I
4	"	I	I	I	I	I
5	6"	I	F	F	F	F
6	"	I	I	I	I	I
7	9"	I	I	F	F	F
8	"	I	I	I	I	I

I - Invisible F - Faint V - Visible

difference between best possible registry and just satisfactory registry may mean the difference between locating or failing to locate a defect in practice, it will be best if the least distances are chosen not too much less than the distances of best registry. Accordingly, in both Figures 7 and 8 an arbitrary visibility limit was chosen and indicated therein by a dotted line. It may be noted that the general visibilities for the 100 and 250 mg. sources will exceed this limit at the larger distances in both the cases of 1- and 3-inch sections. In accordance with what has been said above, the limit indicated by the dotted lines was taken as not much less than maximum visibility for the two sources giving the lowest maximum.

Table 11 lists the distances obtained from these curves for the distances of best overall registry determined by positions of peaks in the curves and also the minimum practical working distances at which good registry is possible. The latter distances were determined mainly by the points at which the arbitrary dotted visibility limit line crosses the rising part of the curve. The values were taken as rounded numbers and the nature of the data taken into consideration in choosing the nearest integers. These figures are shown plotted in Figure 9 against the corresponding source strengths and present a fairly systematic relationship for the minimum practical working distances. The curve giving the distance for maximum registry is also fairly regular for the 1-inch steel section, but not quite so for the 3-inch steel section, because the maximum relative visibilities at the peaks differ much more between the 250 and 500 mg. sources than it does in the case of the 1-inch section. It is likely that the position of the peak in the case of the 250 mg. source (3-inch steel) has been taken too large. The distribution of data points is such that almost the peak value is reached at 20 inches. Using this distance for the distance of maximum registry for the 250 mg. source with 3 inches of steel, a sensible curve may be drawn for the 3-inch section as well. There is no doubt that there is a factor present which limits the maximum sensitivity that might be obtained with a 500 mg. source by simply increasing the working distance indefinitely. The curve for the 500 mg. source in Figure 8 definitely shows no improvement as the working distance is increased beyond 20 inches, and it is this value that has to be entered in Table 11 instead of an expected higher one.

Table 11

Source to Film Distances for Maximum Defect Registry and Minimum Practical Working Distances for Radium Sources of Various Strengths and Steel Thicknesses of 1 and 3 inches

(a) 1" Steel Section

Source	Distance of Max. Registry	Least Distance for Practice
25	10	6
100	12	8
250	14	10
500	18	14

(b) 3" Steel Section

Source	Distance of Max. Registry	Least Distance for Practice
25	12	9
100	14	10
250	24	12
500	*	16

*The distance of maximum registry as shown in Plate 8 comes at 20", but the visibility is inferior to that for the 250 mg source at 24". In this investigation the data show little improvement between 16 and 40" working distance, although this might be expected from theory. Table 3 (b) gives 32.5 inches as the minimum distance from umbral registration of 2 per cent spherical defects.

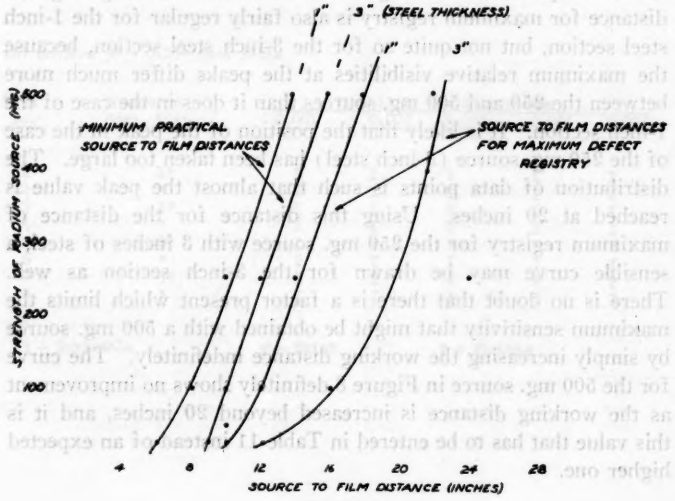

FIGURE 9.

All the observations contained in Tables 5 to 8 and expressed in the curves of Figures 6 to 9 are in terms of visibility of a defect without regard to its sharpness or definition. Due to the lower inherent contrast in gamma radiographs, it cannot be expected that images having the sharpness of those obtained in x-ray work will ever be obtained. However, there will be an optimum definition in gamma radiographs which will depend very largely, as explained earlier in this report, on the prevailing geometrical conditions. The definition will depend upon how much of the defect is registered by its umbral shadow or by its penumbral shadow or both. In Table 3(c) we have seen that penumbral registration may take place at almost any of the distances ordinarily employed in gamma radiography and it is only natural to ask to what extent the defect images which have given the main data are due to or augmented by penumbral registration. A study of Table 3(b) will show that the minimum distances required to give umbral registration of 4 per cent spherical defects in a 1-inch section are all equal to or greater than the distances given in Table 11, section (a), while for the three-inch section, the corresponding distances are all less. Thus 4 per cent deep 4 per cent wide defects in the 1-inch plate, when they showed at all on the test radiographs, were due to penunmbral registration, while in the 3-inch test plate the registration of the small defects must have been mainly umbral.

In view of these facts and for the sake of completeness, all of the radiographs were reviewed to study the image characteristics for one of the holes in each test plate. Hole No. 1 was chosen because its location was best established by markers on the test block. In the 1-inch test plate this was about 5 m m in diameter, in the 3-inch block about 3 m m in diameter. In the case of the former, there was little point in studying a 4 per cent deep 4 per cent wide hole because it was seldom recorded, so that a wide hole of this depth was used instead. In the case of the latter the No. 1 hole was just that desired (4 per cent by 4 per cent). In studying the radiographs the apparent or image diameter was measured as well as possible by means of jaw calipers and recorded in Table 9 along with the observed character of the defect image. To determine how much of each defect image was due to umbral registration, the true umbral diameters of the defects were calculated for each combination of source, distance, and steel thickness, and

included in the table, together with the reciprocals of the merit figures $d/t\phi$ which, as explained earlier in this report, give directly the widths of the penumbral haze around the central part of the image. Twice this width, or $2t\phi/d$ plus the calculated umbral diameter, is the total image diameter that we may expect to see. These total diameters were computed and included in the table. In Section (a) (25 mg. 1-inch test plate) it may be noted that the measured diameters are, with the exception of the first one, only slightly greater than computed umbral diameters. Thus the registration is mainly umbral. The computed total diameters in this case are in quite good agreement with observed diameters at distances of 12 inches and more. It may be noted from this section of the table that as long as the observed diameter is close to the computed umbral diameter the defect image is good.

In Section (b) the same sort of relationship may be found, except that at 4 inches no umbral registration is possible, and it is not surprising that no defect image is observed. Here again we see that as the true umbral diameter approaches the observed diameter the definition of the defect image increases.

The data of Table 9 for radium sources of 100, 250 and 500 mg. strength all show the same interesting relation between image characteristics and values of the true umbral diameter. In cases where no true umbral diameter existed no image was observed and the general quality of the image increased as the true umbral diameter approached the observed image diameter. Stated inversely the image quality improved as the width of the penumbral haze decreased. This width was shown above to be equal to twice the reciprocal of the merit figure $d/t\phi$. In general the conclusions to be drawn from Table 9 are the same as those obtained in the review of the data of Tables 5-8 in which only the general visibility of an object in the radiograph was correlated with the source to film distance and source size.

In concluding the discussion of Table 9 and its implications, it must be said that at all of the distances in Figure 9 which have been chosen as representing the minimum practical distance at which the radium sources of various sizes may be used, the definition as determined from the remarks in the table is satisfactory enough for practical purposes. At these distances a certain amount of edge haze will be present because the definition may not

be up to its maximum possible. These distances in Figure 5 and Table 11 which represent the distances at which maximum defect visibility is achieved are with two exceptions distances at which the definition according to Table 9 is good. In the two exceptions (25 mg. at 12 inches and 3-inch steel, and 100 mg. at 12 inches and 1-inch steel) there is still a slight lack in definition to be expected due to differences in the true umbral and observed diameters, but hardly warrants a change in the figures.

In Table 10 the type of defect is quite different from those forming the basis of the preceding tables. Here the defect is a crack of small width with its depth in line with the source. The depth was 1/4 inch and the width varied between .001-.005 inches. It is shown that when the crack has a width of .001 inch no image of it was registered for any position of the 100 mg. source when used with the three-inch section. Registry began for the 1-inch section at 6-inch working distance. Increasing the width of the crack to .002 and .003 inches in the 1-inch plate made possible the detection of this defect at the small working distance of 3 inches. In the case of the three-inch block this did not seem to decrease the distance of registry. These results are interesting but it may be seen that the use of defects of this type will not help in determination of minimum source to film distances for defects of roughly spherical shape such as found in porosities and cavities. It should be emphasized furthermore that the angle which the plane of the crack makes with the direction of the radiation determines very largely whether or not the defect will be registered. Wide defects such as open laminations whose plane is normal to the direction of the radiation cannot be detected in a radiograph. The data of Table 10 assure us that a fine crack of appreciable depth and inclined at not too great an angle from the direction of the beam will be observed at any of the minimum working distances listed in Table 1.

Conclusion.

A careful study was made of existing radiographic literature to determine to what extent research either in x-radiography or gamma radiography had given data which could be applied to the present problem. It was found that considerable interest has been shown, both here and abroad, especially from the x-ray

standpoint, and that considerable geometrical analysis of the exposure conditions to be found in radiography has been made. These works have been reviewed as concisely as possible and the general principles laid down were used in analyzing the empirical results obtained.

Experimental studies were carried out on one- and three-inch thick steel test blocks and with four radium sources representative of the sizes of radium sources used in gamma radiography, namely, sources of 25, 100, 250 and 500 mg. strength. These test blocks, containing in their faces a variety of small artificial defects were radiographed, using standardized technique, at a number of source to film distances which cover the range of distances which are to be found in practice. The radiographs obtained were studied for both the contrast and definition of each of the defect images. Curves and tables have been drawn up which indicate those working distances at which maximum contrast or definition is obtained, and also some working distances are indicated which are deemed to be the least possible for practical gamma radiography. These distances allow a certain saving in radiographic exposure time over the distances now specified in some cases.

A comparison of the empirical data with the theoretical material mentioned earlier has revealed some points of technical interest which may be briefly summarized as follows:

(*a*) It has been found that a geometrical figure of merit may be correlated with the quality of the radiographic registry. The value of this figure for any particular radiographic set-up will give a fair index of the radiographic registry that may be expected. This figure of merit given by $d/t\phi$ (in reciprocal m m) when equal to or greater than 1.5 gives good registry in 1-inch steel sections, and when equal to or greater than 1.0 gives good registery in three-inch steel sections. Strictly speaking, this figure of merit applies to the definition of a radiographic image rather than to its contrast.

(*b*) It has been found that the images of small defects have their maximum visibilities as determined by contrast at distances which in the case of the three-inch steel sections are definitely less than the distances at which greatest radiographic definition is to be expected. This indicates the presence of another factor in the experimental conditions which is associated with the scattering of

the radiation in the air and in the test piece, and possibly also with the spreading in the course of time of an image in the photographic emulsion.

(*c*) While it is shown in theory that registration of a defect by means of a purely penumbral radiographic shadow is possible, it was found in this work that in almost all cases in which the registration of a defect took place mainly by its penumbra the image was very poor and probably worthless for practical work. It was found, however, that as soon as an appreciable fraction of the image diameter was due to a purely umbral shadow, the visibility of the image was good even though the definition was not at its best. As mentioned before, this visibility increases with working distance up to a certain point and then either ceases, or even falls again, even though definition itself may be improving at the same time. As a result of these conditions, there exist in gamma radiography practical optimum distances at which the visibility of the defect is at its maximum.

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FACTOR OF SAFETY AND WORKING STRESSES OF MARINE PROPULSION SHAFTING.

By R. Michel, Member.

Mr. Setz' paper in the November 1941 issue of the Journal, *entitled "The Influence of Corrosion on Propeller Shaft Maintenance," gives the impression that current shafting is designed with a factor of safety of the order of 9. This is true only in the shaft body and when steady shearing stress alone is considered. The present paper points out that additional stresses exist, and gives a discussion of the influence of these on the mode of failure and the factor of safety, which now becomes of the order of 2.*

Progress in our knowledge of the mechanics of materials and dynamics has made it possible to supersede the older and more empirical methods of designing marine propulsion shafting by methods which are more rational. An examination of many failures of shafting over a period of some 30 years shows the initial stages of all of these to have been due to fatigue, which type of failure occurs only under repeated or alternating stresses.

A large percentage of the failures was aggravated by the influence of corrosion on the endurance limit of the shaft material. In all cases the primary failure started at a point of high localized stress, due to a discontinuity or sudden change in cross-section. Since alternating stresses always exist in shafting, it is necessary to carefully evaluate these as well as the steady stresses if a rational design is to be followed. Empirical design methods give but scant attention to vibrating stresses and do not take into account the influence of high localized stresses on the strength of the shafting.

The stresses in propulsion shafting may be classified as steady

and alternating stresses. The former consist of the shearing stress due to steady torque and the compressive stress due to steady thrust of the propeller. The alternating stresses are made up of the bending stress, which is completely reversed in one revolution, vibratory shearing stresses, which superimpose a fluctuating component upon the steady shearing stress, and a variable compressive stress, which is generally ignored in design calculations, due to its low value.

Vibratory stresses always exist in propulsion shafting, regardless of the type of drive, since these are excited by the propeller even though the engine torque is constant. The vibratory torque varies with the shape of the stern of the vessel and has a value of about 7½ per cent of the mean torque for propellers operating behind a rounded stern and about 15 per cent for propellers behind a skeg.

Four types of drive are generally employed on naval vessels:

(*a*) Geared steam turbine drive.

(*b*) Geared Diesel engine drive, with or without hydraulic coupling.

(*c*) Electric drive.

(*d*) Direct connected Diesel engine drive.

In the first three types, alternating torque is excited only by the propeller and has values as indicated above. However, dangerous torsional critical speeds may exist within the operating range of the shafting of a direct connected Diesel engine drive and the resulting high alternating shearing stress must be eliminated or reduced.

The shafting is first designed for the full power condition, at which the steady shearing stress and the compressive stress due to thrust are a maximum. The design is then checked for stresses at the torsional critical speed. The shearing stresses due to alternating and steady torsion, must be computed at the critical speed. The compressive stress due to thrust will be lower than at full power, whereas the alternating bending stress remains constant over the whole range of operation, since it is a function of the dead weight of the parts and the spacing of the bearings.

Since shafting materials are ductile, the steady stresses are

combined in accordance with the maximum shear theory of failure, as follows:

$$S_{s.r.} = \sqrt{S_c^2 + (2S_s)^2} \qquad (1)$$

where $S_{s.r.}$ = steady stress resultant, p.s.i.

S_c = compressive stress due to thrust.

S_s = shear stress due to steady torque.

Stress concentration factors are not used in equation (1) since high localized stresses will cause failure only under conditions of repeated or variable stress. Since the maximum shearing stress in a bar subjected to compression is one-half of the compressive stress, the shear stress must be multiplied by two to give the equivalent compressive, or tensile stress. Due cognizance of this is given in formula (1).

The alternating shearing stress excited by the engine, as is the case in direct Diesel engine drives, is a function of the shearing modulus of elasticity of the shaft material, the shaft diameter and length, the vibration amplitude at the propeller and the mass moments of inertia of the engine and propeller. This stress is generally negligibly small at speeds well removed from the critical but must be computed at the critical speed. The alternating stresses are then combined in accordance with the relation:

$$S_{a.r.} = \sqrt{(k_b S_b^2) + (2k_t S_s)^2} \qquad (2)$$

where $S_{a.r.}$ = alternating resultant stress, p.s.i.

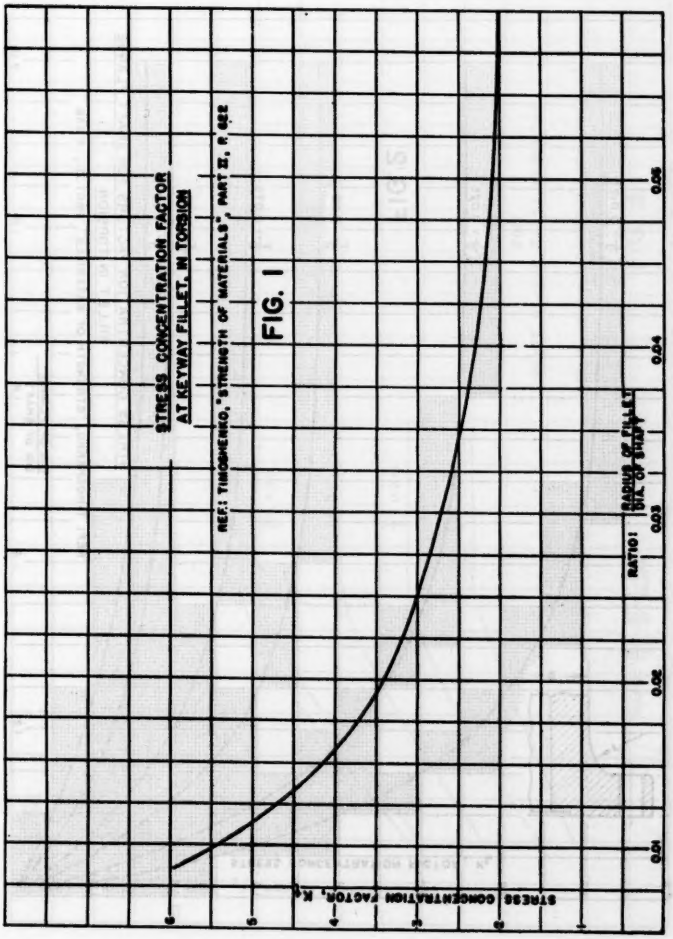
S_b = bending stress, p.s.i.

S_s = alternating shearing stress, p.s.i.

k_b = stress concentration factor for bending.

k_t = stress concentration factor for torsion.

The points of greatest stress concentration occur at the corners of keyways and at the fillets that join the shaft flanges with the shaft body. Experimental studies have been made and published which give values of these stress concentration factors as a function of the ratio of fillet radius to shaft diameter. Values of stress concentration factors are given in Figures 1, 2 and 3. Referring to Figure 2, for example, we observe that if the ratio


STRESS CONCENTRATION FACTOR AT KEYWAY FILLET, IN TORSION
REF.: TIMOSHENKO, "STRENGTH OF MATERIALS", PART II, P. 482
FIG. 1
STRESS CONCENTRATION FACTOR, K_s
RATIO: RADIUS OF FILLET / DIA. OF SHAFT
0.01
0.02
0.03
0.04
0.05

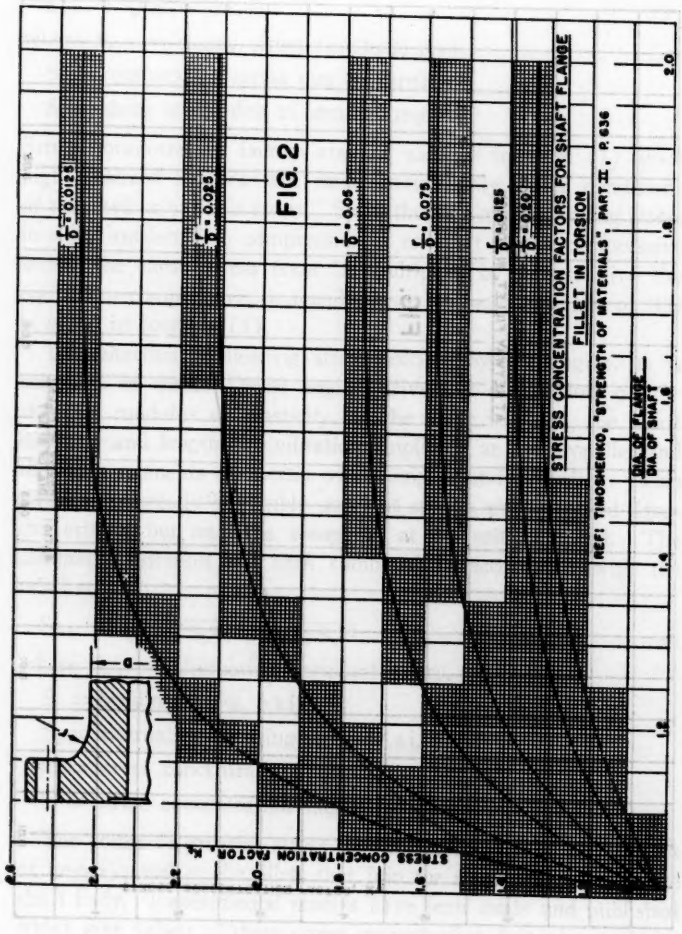
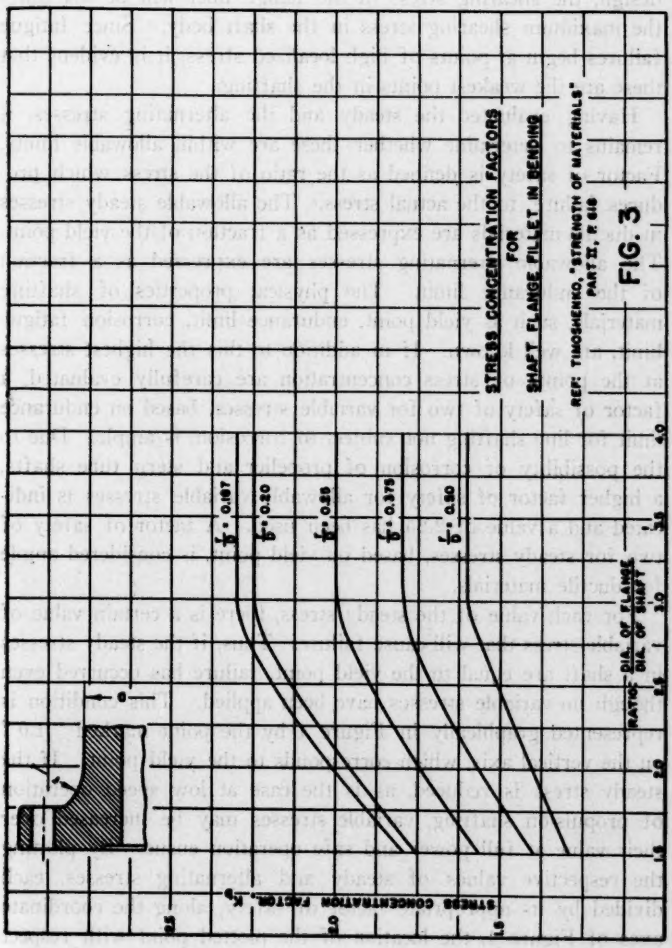


FIG. 2
STRESS CONCENTRATION FACTORS FOR SHAFT FLANGE
FILLET IN TORSION
REF: TIMOSHENKO, "STRENGTH OF MATERIALS", PART II, P. 636
DIA. OF FLANGE / DIA. OF SHAFT
r/d = 0.0125
r/d = 0.025
r/d = 0.05
r/d = 0.075
r/d = 0.125
r/d = 0.20
STRESS CONCENTRATION FACTOR, K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
2.0
1.8
1.6
1.4
1.2
r
d


STRESS CONCENTRATION FACTORS
FOR
SHAFT FLANGE FILLET IN BENDING
REF: TIMOSHENKO, "STRENGTH OF MATERIALS"
PART II, P 618
FIG. 3
STRESS CONCENTRATION FACTOR, K
RATIO DIA. OF FLANGE / DIA. OF SHAFT
r/d = 0.167
r/d = 0.20
r/d = 0.25
r/d = 0.375
r/d = 0.50
d
r

of the diameter of the flange of a shaft to the diameter of the shaft is 1.6, and if a value of $r/D = 0.0125$ is employed in the design, the shearing stress in the flange fillet will be 2.4 times the maximum shearing stress in the shaft body. Since fatigue failures begin at points of high localized stress, it is evident that these are the weakest points in the shafting.

Having evaluated the steady and the alternating stresses, it remains to determine whether these are within allowable limits. Factor of safety is defined as the ratio of the stress which produces failure, to the actual stress. The allowable steady stresses in ductile materials are expressed as a fraction of the yield point. The allowable alternating stresses are expressed as a fraction of the endurance limit. The physical properties of shafting materials, such as yield point, endurance limit, corrosion fatigue limit, are well known. If in addition to this the highest stresses at the points of stress concentration are carefully evaluated, a factor of safety of two for variable stresses, based on endurance limit for line shafting not subject to corrosion, is ample. Due to the possibility of corrosion of propeller and stern tube shafts, a higher factor of safety for allowable variable stresses is indicated and a value of 2.25 has been used. A factor of safety of two for steady stresses, based on yield point, is considered ample for ductile materials.

For each value of the steady stress, there is a certain value of variable stress that will cause failure. Thus, if the steady stresses in a shaft are equal to the yield point, failure has occurred even though no variable stresses have been applied. This condition is represented graphically in Figure 4 by the point marked "1.0" on the vertical axis, which corresponds to the yield point. If the steady stress is reduced, as is the case at low speed operation of propulsion shafting, variable stresses may be increased over their value at full power and safe operation ensue. By plotting the respective values of steady and alternating stresses, each divided by its appropriate factor of safety, along the coordinate axes of Figure 4, the location of the plotted point with respect to the heavy and the dotted diagonal lines will give an indication of safe operation. Actually, the diagonal lines shown should be curved convexly when viewed from above, but the straight line

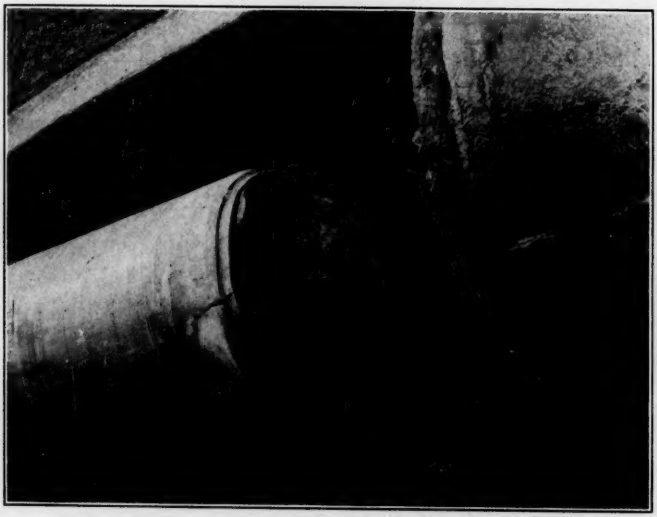
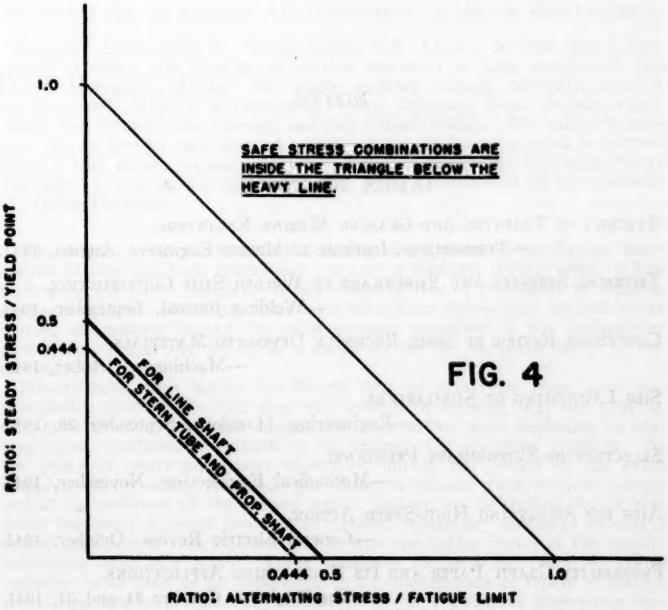


FIGURE 5.—TYPICAL PROPULSION SHAFTING FAILURE.



approximation shown simplifies the representation and errs on the side of safety.

The foregoing discussion of shaft failure is based wholly upon limiting steady and variable stresses to a certain percentage of the yield point and fatigue limit of the material. In addition to this, it it necessary to check the design for whirling speed, which should be at least fifteen per cent above the running speed. Whirling speed is a function of the shaft diameter and the distance between bearings.

It is clear, therefore, that a rational method of propulsion shafting design should be one that may be applied to all types of drives. It should take due cognizance of the method of failure, which is a fatigue failure in the early stages and a shear failure in the latter stages (see Figure 5). Furthermore, if a light and yet safe design is to result, great care must be taken to remove, or reduce to a minimum, all points of stress concentration.

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SYSTEMS OF TRAINING AND GRADING MARINE ENGINEERS.

Engineer Commander D. Hastie Smith, R.N. (Rtd.), believes that a new system of entry and training of marine engineers is long overdue in the British Mercantile Marine. He briefly reviews systems currently used in the Mercantile Marines of Denmark, France, Germany, Great Britain, Italy, Japan, the Netherlands, Sweden, and the United States. The author's purpose was to present such facts as would have to be borne in mind in formulating a new scheme to meet the future requirements of the Merchant Navy. His paper is reprinted from the August, 1941, Transactions of the Institute of Marine Engineers.

The present system of entry and training of engineers in the British Mercantile Marine has been established for over a century, during which it has undergone but slight changes. It has produced tens of thousands of efficient marine engineers, including many who have been universally recognized as worthy of ranking among the most eminent members of the engineering profession. It has also served as a model for all the merchant navies of the world.

Nevertheless, even before the World War of 1914-1918, there were unmistakable signs of the fact that this system of training was not proving wholly satisfactory and that engineering apprentices were beginning to display some reluctance to embark on the calling of a sea-going engineer. In the post-war years and, more especially, during the period of the great shipping slump which followed, the situation became progressively worse, and at the outbreak of the present war it had grown so serious that it was found necessary to have recourse to various emergency measures to obtain junior engineers in sufficient numbers to man the engine rooms of the rapidly expanding Merchant Navy. These measures included the entry of young engineers with little or no experience in the maintenance or repair of marine machinery, and of a temporary relaxation of the regulations concerning certificates of competence by the introduction of Provisional Certificates.

Various suggestions and schemes for reform have already been put forward in the technical press, but the attitude of the senior members of the marine engineering profession has, it is said, offered little encouragement to would-be reformers. The two main causes of the present position are the shortage of junior engineers due, in a large measure, to the decline of the apprenticeship system in the engineering trade generally, and to the inferior standard of technical and general education displayed by a regrettably large proportion of such apprentices as offer themselves for employment as junior engineers.

A further decline of the apprenticeship system in British shipyards and marine engineering works will certainly have to be faced in the coming years, if the views of some leading shipbuilders and engineers on the matter are to be accepted as correct. A small number of entries of young marine engineers in search of sea-going experience will doubtless always be forthcoming, but there is every likelihood that this will be totally inadequate to meet the normal annual requirements.

As regards complaints from chief engineers at sea of the poor standard of technical and general education displayed by some of the newly-entered junior engineers in an age when the general standard of education in this country has undergone such a marked improvement, the charges of lack of sympathy on the part of those who control the professional destinies of their subordinates have, perhaps, not always been wholly devoid of foundation. Unlike his predecessor of the last generation who almost invariably owed his promotion to long service and personal merit, the superintendent engineer of the present day is frequently a younger man who has reached that position

through his outstanding professional ability. Can it be wondered, therefore, that he is not always able to share the views of some of his less talented colleagues and to understand the reluctance of an engineering apprentice to take the fullest advantage of the educational facilities available to him in the shape of evening classes; or that he is unable to appreciate the reason why a junior engineer at sea does not devote his scanty leisure to the study of mathematics and applied mechanics?

It has also been pointed out that unfavorable prospects in the matters of pay, status and conditions of service of sea-going engineers deter some of the most promising apprentices from taking up a seafaring life. The importance of these questions is undeniable and it is clear that they have a vital bearing on the whole problem of providing engineers for the Merchant Service. It is to be hoped that the improvements in rates of pay which have recently been introduced will be maintained after the war, together with the new system of continuous employment adopted for all officers of the Merchant Navy. Some improvements in the conditions of service of sea-going engineers are called for before any revised system of entry and training can be expected to prove satisfactory. Whereas the working conditions in the engineering industry ashore have improved beyond all recognition during the last thirty years, nothing comparable has taken place in those which marine engineers are called upon to endure, and such improvements as have been effected are almost entirely due to the technical progress which has been made in the manufacture and design of machinery, and not to concessions granted by shipowners. If the sea-going engineer of the future is to be trained and educated as a technician, he must be treated as such instead of as a skilled mechanic—more especially as no skilled mechanic employed ashore would be expected to tolerate the working conditions which ships' engineers are required to accept as a matter of course. It has frequently been pointed out that whereas the engine-room staff of any British merchant ship should be prepared to undertake the maintenance of the machinery in their charge insofar as it concerns running defects and emergency repairs, or the carrying out of routine examinations and adjustments, they should not be expected to undertake general overhauls of the kind which normally devolve on the shore staff of a liner company. The Report of the U. S. Maritime Commission on Training Merchant Marine Personnel contains an allusion to the fact that "the cost of shipyard repairs in British vessels is much less than for identical American ships. The British engineer with years of repair apprenticeship behind him is expected to accomplish much aboard and make only major repairs in a shipyard."

It is significant that the reduced cost of upkeep of machinery due to the labor of the engineering personnel of British ships is not reflected in the ability of the latter to compete with the vessels of several other maritime nations who do not require so much of their marine engineers and who have found it necessary to train these in a somewhat different manner to perform precisely the same duties as their British colleagues.

The old-established British system of training marine engineers was originally regarded as the only sound method of producing practical and efficient Merchant Service engineer officers, and it was an axiom that the only way to acquire the practical knowledge essential for that purpose was "to go through the shops." Similar views prevailed in other maritime countries, but it is a remarkable fact that in almost every instance the latter have gradually broken away from this tradition and have preferred to adopt a more liberal and scientific scheme of education and training for the young engineers who man the engine rooms of their merchant ships. No British marine engineer will deny that the professional reputation of the sea-going engineers of those countries stands high and that it compares favorably with that of the marine engineers and naval architects responsible for the design

and construction of the passenger and cargo vessels built on the Continent and in America during the last few years.

Before proceeding to discuss the nature of the changes which it might be thought desirable to effect in the present system of training marine engineers in this country, it is proposed to make hereunder a brief survey of the various systems of training and grading of engineers in the Mercantile Marine of the principal maritime nations in force just before the outbreak of war. These, taken in alphabetical order, are those of Denmark, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden and the United States.

Denmark.

The principal engineers' school is in Copenhagen, but there are eight smaller ones in other parts of Denmark. These establishments are supported by State and municipal funds.

The duration of the courses in educational and technical subjects is one year for students who intend to seek employment as engineers in small vessels, and two years for those who are desirous of serving in passenger ships. A candidate for admission to one of these schools must have served an apprenticeship of at least three years' duration in an engineering works, during which he must have been employed for not less than one year on the manufacture and repair of marine engines. He must also have had at least four years service in the engine rooms and stokeholds of sea-going ships, including three months service as a fireman.

On completing the course at the engineers' school and passing the prescribed examination, the student goes to sea as an assistant engineer. After a minimum period of two years' service as such, he is entitled to present himself for a practical examination to test his ability to operate and maintain main and auxiliary engines and boilers of sea-going ships. After passing this test he receives a Second Engineer's certificate.

A professional examination must be passed by a Second Engineer desirous of obtaining a Chief Engineer's certificate, and an Extra Chief Engineer's certificate is required should he wish to seek employment as chief engineer in charge of the machinery of an ocean-going vessel engaged in the emigrant trade. The duration of the qualifying sea service of engineers seeking to obtain these higher certificates includes a period of not less than two years with a Second Engineer's certificate.

Although the minimum period of the apprenticeship to be served in an engineering works is laid down as three years, practically all Danish marine engineers serve a full apprenticeship of five years, this being a requirement of the shipowners' superintendent engineers.

Except for the obligatory course of study to be undergone at one of the engineers' schools, the Danish system of entry and training of mercantile marine engineers is not unlike that obtaining in this country.

France.

There are three grades of engineers in the French Mercantile Marine, in addition to engineer cadets (*Elèves officiers-mécaniciens*) under 21 years of age.

A candidate desirous of being examined for a Third Engineer's certificate must be over 21 years of age and must *either* have served as an assistant engineer at sea for not less than four years, *or* have been employed for a period of at least two years in an engineering works engaged in the construction or repair of marine engines *and* have at least two years' sea service as an assistant engineer.

A Third Engineer's certificate may be either for steam or for motor vessels and entitles the holder to serve as second engineer in any steamship (or motorship) with engines of up to 1000 I.H.P.; as chief engineer of any steamship (or motorship) with engines of up to 300 I.H.P.; and as chief engineer of any fishing vessel with engines of up to 400 I.H.P.

A holder of a Third Engineer's certificate having not less than five years' sea service as second engineer of a ship or ships with engines of or above 300 I.H.P., may also serve as chief engineer of any steamship (or motorship) with engines of from 300 to 500 I.H.P.; and as chief engineer of any fishing vessel with engines of from 400 to 700 I.H.P.

A Third Engineer's certificate is usually obtained only by an engineer wishing to serve in fishing vessels or other small craft, and its possession does not necessarily represent the first step towards promotion to a higher grade.

A candidate for a Second Engineer's certificate must be not less than 18 years of age and must pass a qualifying examination in theoretical and practical subjects. He is also required to produce evidence that he has been employed for a period of at least two years in engineering works engaged in the construction and repair of marine engines and that he has served as an assistant engineer in a sea-going ship or ships for not less than two years.

A holder of a Second Engineer's certificate who has served at sea as second engineer for a period of two years or one year (according to the power of the propelling machinery) may serve as chief engineer of any ship with engines of from 300 to 1400 I.H.P. He may also serve as chief engineer of any ship with engines of or below 700 I.H.P., provided that he is 24 years of age and has served as second engineer of a sea-going ship or ships for a period of at least one year since obtaining this certificate.

Every French merchant ship with engines of from 1400 to 2000 I.H.P. must carry a second engineer who holds a Second Engineer's certificate and a similar certificate must be held by every engineer in charge of a watch in a ship with engines of from 2000 to 4000 I.H.P.

A candidate desirous of being examined for a First Engineer's certificate of competency must be over 24 years of age and possess the following qualifications:

(*a*) He must be the holder of a Second Engineer's certificate and have not less than two years' sea service as an engineer in charge of an engine room watch; *or*

(*b*) He must be a duly qualified engineer cadet with not less than three years' sea service, of which at least two years must have been spent as an engineer officer of the watch or an assistant engineer officer of the watch; *or*

(*c*) He must be a graduate of an engineering college (of university status) with not less than one year's sea service as an engineer cadet.

Every French merchant vessel with engines of or above 1400 I.H.P. must carry a chief engineer who holds a First Engineer's certificate.

Engineer cadets in the Mercantile Marine are recruited from students who have completed a course of study at an intermediate technical school or from engineering apprentices with at least two years' experience as such in an approved engineering works. They must be over 18 years of age and pass a qualifying examination in a number of technical and educational subjects, in addition to undergoing tests in workshop practice, etc. Successful candidates obtain diplomas as engineer cadets and after not less than one year's sea service as such, during which they must be employed as engine room watchkeepers, they may serve as engineer officer of the watch within the limits laid down for holders of Second Engineers' certificates, provided they are not less than 21 years of age and obtain satisfactory reports on their progress and conduct.

The National Schools of Maritime Navigation at Havre, Nantes and Marseilles give a two-year course of instruction in technical and educational subjects and workshop practice to boys wishing to be prepared to take the engineer cadets' examination. Admission to these schools is by competitive examination open to boys of 16. No tuition fees are charged, and scholarships are awarded by the State to boys who are members of large families or whose families have limited means. The three national schools referred to above, as well as those at Boulogne and Bordeaux, also have short courses for sea-going engineers preparing to take the examination for First and Second Engineers' certificates.

Most of the students do two years' service in the French Navy after completing their courses at the national schools.

The retiring age for officers in the French Mercantile Marine is lower than in most other merchant services. The French Line, for example, compels its officers to retire at 55 years of age, while another leading company permits retirement at 50 years, after 25 years of service. The effect of this early retiring age is reflected in the improved prospets of younger officers and their comparatively rapid advancement.

On the other hand, the various engineers' examinations are said to be far more stringent than those taken by marine engineers in this country, as may be judged from the large number of candidates who fail to pass. During a recent year, the following numbers were examined:

Examination	*Total No. of Candidates*	*Successful Candidates*	*Per Cent Successful*
Engineer Cadets	245	24	Under 10
Second Engineers	499	90	18
First Engineers	155	74	50

It is estimated that the annual requirements of the French Mercantile Marine amount to about 100 young engineers and engineer cadets.

The *Brevet Supérieur d'Officier Mécanicien*, equivalent to the British Extra-Chief Engineer's certificate, was abolished about 15 years ago.

Germany.

There are two grades of engineers in the German Mercantile Marine, *viz.*, *Schiffsingenieur II* (chief engineer) and *Schiffsingenieur I* (extra chief engineer), for which certificates are issued to qualified candidates who succeed in passing the necessary examinations in technical and educational subjects.

A candidate for a certificate as *Schiffsingenieur II* must possess the following qualifications:

(1) He must have served an apprenticeship of at least three years in an engineering works after completing his fifteenth year;

(2) One year of this apprenticeship must have been served in a large engineering works or shipyard of the type of Blohm & Voss, Deschimag, A. G. Weser, A.E.G. or M.A.N.;

(3) He must have served at sea as a junior engineer on board sea-going steamships or motorships for at least two-and-a-half years, of which one year must have been served in a steamship; and

(4) He must have completed a course of study extending over a period of at least three sessions, each of six months' duration (including vacations), at a recognized engineering college.

After passing the examination for the grade of *Schiffsingenieur II*, an engineer who wishes to obtain a certificate as *Schiffsingenieur I* must possess the following additional qualifications before presenting himself for the statutory examination for this grade:

(1) He must have served at sea as chief engineer in charge of the machinery of a sea-going steamship or motorship for at least two years; and

(2) He must have completed a further course of study extending over a period of at least two sessions, each of six months' duration (including vacations), at a recognized engineering college.

It will be seen, therefore, that a candidate for a certificate of the lower grade must be at least 22 years of age, and that an engineer will be at least 25 years old before he can obtain a certificate of the higher grade.

The system of training appears to make excellent provision for the technical instruction of engineers in charge of the machinery of ships, but unlike the British system, it does not seem to provide certificated engineers for service as watchkeepers.

ITALY.

The Italian Government maintains 17 nautical schools for training young men as deck and engineer officers in the Mercantile Marine. These schools are supervised by the Ministry of Education and charge no tuition fees.

Each school gives a four-year course of instruction to students desirous of becoming deck officers or engineers in the Merchant Service, as well as to those studying shipbuilding with a view to entering the Royal Superior Naval School at Genoa for the purpose of taking a four-year course in naval architecture. The total annual enrolment in the nautical school is about 500, the engineer students numbering approximately 35 per cent of this total. About half the graduates enter the Merchant Service, and of this number 80 per cent secure employment in cargo vessels, etc., and the remainder in passenger liners.

The course of instruction prescribed for the engineer students covers a wide range of educational and technical subjects, in which periodical examinations are held. After passing out from one of these schools an engineer student must serve at sea for two-and-a-half years as an engineer cadet before he becomes entitled to a Second Engineer's certificate. No Government examinations are held for the grades of first engineer or chief engineer, and a candidate for a certificate as such is merely required to prove that he is an Italian subject, has graduated at a nautical school, is not less than 21 years of age, and has completed four years' sea service while holding a Second Engineer's or First Engineer's certificate.

An unusual feature of the Italian method of training marine engineers is the apparent lack of any organized system of workshop training. The curriculum of the nautical schools includes instruction in workshop practice, but beyond this the engineer students do not appear to receive any practical training of the kind which British marine engineers undergo.

The Italian system of entry and training of Mercantile Marine engineers seems to differ from that which obtains in this country to a greater extent than that of any other maritime nation.

JAPAN.

Engineer officers in the Japanese Mercantile Marine are divided into four main grades, viz., third, second and first engineers, and chief engineers. The certificates for these grades may be either steam or motor, and special certificates—of both kinds—are also issued to third and second engineers serving in coasting vessels. Third engineers serving in very small motorcraft may also obtain a special certificate as such.

Technical examinations are prescribed for marine engineers who wish to obtain any of the above certificates, but graduates of the nautical colleges are not required to take these examinations.

Training establishments for deck and engineer officers are of two kinds—nautical colleges (at Tokyo and Kobe) and mercantile marine schools (there are eight of these in various provincial cities, but not all of them have facilities for training engineers).

A candidate for admission to a nautical college must be under 21 years of age and hold the Japanese equivalent of a British School Leaving Certificate. He is required to pass an extremely stiff entrance examination, which is both competitive and selective. Only about 12 or 13 per cent of the candidates are successful, and before final acceptance as probationary students they are required to pass a rigorous medical examination. The period of training extends over five-and-a-half years and the only charge is an entrance fee of about 12 pounds, which may be paid in small instalments. Students at the nautical colleges and marine schools automatically become members of the naval reserve on enrolment and continue as such until they reach the age of 53. Resignation from the college is only permitted in exceptional circumstances. The curriculum embraces a wide range of technical and educational subjects, including foreign languages (English and German). Practical training comprises the handling of machinery and electric motors, carpentry, boat work and naval instruction, but workshop training is apparently limited to about 10 days per annum, at the commencement of the summer vacation. The daily hours of study are far longer than is usual in any British, Continental or American college, and the daily routine of a Japanese nautical college could not be applied to young men of similar age in this country. Only three years of the total training period of five-and-a-half years are actually spent at the college, as all students have to undergo six months' training at a naval gunnery school, a further six months at a naval dockyard, and twelve months at a private shipyard. Hostels for the accommodation of students undergoing this practical training are maintained by the nautical colleges at six of the principal shipbuilding centers. The twelve months in the shipyard are spent as follows: Two months in the smithery; one month in the coppersmith's shop; three months in the fitting and machine shops; two to three months in the boiler shop; and three to four months fitting afloat. The students work under the supervision of special instructors. The final year of training is devoted to service in the engine rooms of ships belonging to various companies. Shipping companies in receipt of mail subsidies are obliged by law to accept such students (deck and engineer), but all companies are glad to have them on board because they are usually willing workers and are paid very small salaries. While serving afloat students have the status of cadets, *i.e.*, they are over the men but under the ship's officers, who supervise and assist them as much as possible, and every effort is made to give them experience in all the duties appertaining to their respective departments. Arrangements are made to give the engineer students experience on board various ships of widely different types, but they never spend more than six months on board motorships, as experience with different kinds of steam installations is considered more important. On completion of their year's service afloat, students return to their respective colleges to take their final examinations, and if successful, receive certificates as second engineers. After six months' sea service they are granted first engineer's certificates without further technical examination—a medical examination only being required. Promotion to chief engineer is dependent on two years' satisfactory sea service as a second engineer (equivalent to a third engineer in the British Mercantile Marine) or one year's service as a first engineer. No technical examination is prescribed for the Chief Engineer's certificate, but a medical examination must be passed.

Unlike the nautical colleges, which are maintained by the Japanese Government, the mercantile marine schools are maintained and administered by the various Prefectural Governments. A candidate for admission to a mercantile marine school must be between 13 and 17 years of age and in possession of a primary school certificate. He must likewise have spent not less than one year at a secondary school and pass a selective oral examination. A strict medical examination is also prescribed.

The total period of training extends over 7 years 3 months, of which four years are actually spent at the school. School expenses are very low. The syllabus for engineer students resembles that of the nautical colleges, but the instruction is of a more elementary nature. Some complaints on this score have been heard. The practical training comprises six months' naval training at a naval depot and 18 months in naval dockyards and private shipyards under the same conditions as students of the nautical colleges. On completion of their practical training, students go to sea for a year under exactly the same conditions as the students of the nautical colleges, before returning to their respective schools to take the examination for their Second Engineer's certificate and commissions in the naval reserve. Advancement to higher grades is conditional on qualifying sea service and the passing of the necessary technical examinations for certificates as first engineers and chief engineers. Strict medical examinations have also to be passed. A candidate wishing to be examined for a First Engineer's certificate must have at least six months' sea service while holding a Second Engineer's certificate, and a candidate desirous of being examined for a Chief Engineer's certificate must hold a First Engineer's certificate and have at least one year's sea service as a first engineer (corresponding to a second engineer in a British vessel) or two years' sea service as a second engineer (equivalent to a British third engineer).

In addition to the graduates of the nautical colleges and marine schools, there are a number of engineers in the Japanese Merchant Service who have started their sea-going careers as firemen or greasers. The regulations for their entry and advancement prescribe various periods of qualifying sea service and the passing of the necessary examinations, which may be summarized as follows:

A candidate who wishes to be examined for a Third Engineer's certificate must have at least one year's workshop experience and not less than one year's sea service in a subordinate capacity in the engine room of a sea-going vessel. This certificate is intended for engineers of small ships and may also be granted to naval petty officers of the engineer branch with one to three years' service as such, without examination.

A holder of a Third Engineer's certificate becomes eligible for examination for a Second Engineer's certificate after he has served at sea for from one to two years, according to the position he has held and the size of the ship.

A holder of a Second Engineer's certificate may present himself for examination for a First Engineer's certificate when he has completed at least one year's service at sea in a position depending on the size of the ship.

Similarly, an holder of a First Engineer's certificate may be examined for a certificate as chief engineer after he has served at sea for from one to two years in positions depending on the size of the ship.

Engineer lieutenants of the Imperial Japanese Navy may be granted a Chief Engineer's certificate (without examination), engineer sub-lieutenants may be granted a First Engineer's certificate under the same conditions, while acting engineer sub-lieutenants and warrant engineers are entitled to receive certificates as second engineers. The subsequent advancement of such officers is governed by the regulations summarized above as regards sea service and examinations for higher grades.

Four training schools maintained by the Seamen's Aid Association provide technical courses of instruction for firemen and greasers who wish to take the examination for the Third Engineer's certificate, and similar facilities are available at the Osaka Seamen's Training School, which also prepares junior engineers for promotion examinations. A special one-year course has recently been arranged at Tokyo Nautical College and Kobe Nautical College for engineers who are not graduates of the colleges and who are desirous of being prepared for promotion examinations. Enrolment is by selective examination.

Generally speaking, it has been found that engineers who are graduates of the colleges are definitely superior to those from the mercantile marine schools. The latter are younger and their education is usually inferior in the fundamentals of science, mathematics and foreign languages. The most highly favored school is Tokyo Nautical College, which has been established for nearly sixty years. At the present time at least 80 per cent of the chief engineers of the leading shipping companies are graduates of this institution, most of the remaining 20 per cent having been trained in the marine schools. Kobe Nautical College has not been established long enough to enable its graduates to rise to senior positions, as chief engineers of large vessels usually have 16 or 17 years' sea service on appointment as such. The relatively small number of senior engineers who have risen from the ranks are mostly employed by the smaller companies and the coastwise undertakings controlled by the large concerns. Nevertheless, the present shortage of officers is causing many companies to encourage promising marine school graduates and to assist uncertificated personnel of outstanding ability to attend the special courses at Tokyo, Kobe and Osaka. There is also a tendency for the steamship companies in the Kobe area to favor Kobe Nautical College rather than Tokyo Nautical College as regards the employment of junior engineer officers, though both institutions have the same status and shipping companies are primarily concerned with the ability of the individual.

The Japanese system of training young merchant service officers (deck and engineer) is claimed to be the most efficient in the world, but it is probably better suited to the requirements of the Japanese people than to those of young Europeans or Americans. Despite the very lengthy periods of training which the Japanese engineer students undergo, their workshop training cannot be regarded as adequate.

Most of the particulars set out above are taken from the detailed report on the training of personnel for the Japanese Merchant Marine prepared by Mr. B. R. Johansen, U. S. Vice-Consul at Yokohama, which is appended to the U. S. Maritime Commission's Report to Congress on Training Merchant Marine Personnel, of the 1st January, 1939.

NETHERLANDS.

Engineers in the Dutch Mercantile Marine are graded in four categories, *there being four classes of certificate, viz.,* Provisional, "A," "B" and "C" certificate, which are granted to qualified candidates who are successful in passing the prescribed examinations.

A candidate desirous of being examined for a Provisional certificate must be at least 18 years of age and must have served an apprenticeship of at least three years' duration in an approved engineering works, during which time he must have been employed for not less than one year on the manufacture or repair of marine engines and boilers; or else he must hold a diploma from an approved engineering college and produce evidence that he has spent not less than one year as an improver in a marine engineering works.

A special engineers' school is established in Amsterdam and gives students a two-year course in technical and educational subjects, during which they visit ships in port and have access to various shipyards and the Werkspoor Engineering Works. After passing out from the school, students must serve for at least one year in an engineering works before they can obtain a Provisional certificate.

A candidate who presents himself for examination for an "A" class certificate must have spent not less than one year at sea as an assistant engineer with a Provisional certificate.

A candidate wishing to be examined for a "B" class certificate must have at least two year's sea service in steamships or motorships as an engineer with an "A" class certificate.

An engineer desirous of being examined for a "C" class certificate must *either* have served for at least three years as a senior engineer with a "B" class certificate in sea-going steamships or motorships, *or* have served for at least two years as a chief engineer in charge of the machinery of a sea-going steamship or motorship or ships, while holding a "B" class certificate.

From this it will be seen that a Dutch marine engineer must have at least 5 or 6 years' sea service before he can be examined for a "C" class certificate, which corresponds to a British Chief Engineer's certificate.

The examinations for the "B" and "C" certificates include written and oral tests in the English language.

NORWAY.

There are 14 schools for training marine engineers, under the auspices of various municipalities and subsidized by the Norwegian Government, which give the following courses in technical and educational subjects:

(*a*) For Third Engineer's certificates—3¾ months.
(*b*) For Second Engineer's certificates—5 months.
(*c*) For Chief Engineer's certificates—5 months.

Admission to one of these courses is conditional on the possession of certain qualifications. These include the following:

(*a*) A candidate wishing to be prepared for the examination for the Third Engineer's certificate must be not less than 17 years of age and must possess the Norwegian equivalent of a British School Leaving Certificate. He must also have undergone a period of practical training of at least nine months' duration in an approved engineering works and must have spent at least three months in a subordinate capacity in an engine-room at sea.

After completing the prescribed course of study at an engineers' school and passing the qualifying examination, a holder of a Third Engineers' certificate may serve as:

(1) Third engineer of any steamship.
(2) Second engineer of any passenger vessel with engines of or below 300 I.H.P.; of a fishing vessel with engines of any power; or of any other steamship with engines of or below 500 I.H.P.
(3) Chief engineer of a passenger vessel with engines of or below 75 I.H.P.; of a fishing vessel with engines of or below 300 I.H.P.; or of any other steamship with engines of or below 150 I.H.P.
(4) Guarantee engineer of a steamship with new engines of or below 300 I.H.P. in the guarantee time, for a maximum period of 12 months.

(*b*) A candidate for admission to an engineers' school desirous of taking the Second Engineers' course must hold a Third Engineer's certificate and must have served at sea in a position requiring such a certificate for not less than 12 months.

After completing the course of study at an engineers' school and passing the qualifying examination, a holder of a Second Engineer's certificate may serve as:

(1) Second engineer of any steamship.

(2) Chief engineer of any passenger vessel with engines of or below 300 I.H.P.; of any fishing vessel; or of any steamship with engines of or below 500 I.H.P.

(3) Guarantee engineer of a steamship with new engines of any power in the guarantee time, for a maximum period of 12 months.

(*c*) A candidate for admission to an engineers' school who wishes to take the Chief Engineer's course must be the holder of a Second Engineer's certificate and must *either* have 24 months' sea service in a position requiring such a certificate *or* must have served as a third engineer in charge of a watch in steamships with engines of at least 1000 I.H.P. for at least 12 months, in addition to which he must have at least 12 months' sea service as a second engineer in such vessels.

After completing the Chief Engineers' course of study at an engineers' school and passing the prescribed qualifying examination for a Chief Engineer's certificate, the holder of such a certificate may serve as chief engineer in charge of the machinery of any Norwegian steamship.

The regulations concerning motor certificates are similar to those relating to steam certificates, but the qualifying service must have been served in motor vessels.

Third, second and first class motor endorsements (or corresponding steam endorsements) must be obtained successively, with six months qualifying service in motorships (or steamships) for each. Qualifying examinations in oil engines (or steam engines, etc.) must be passed for second and first class endorsements.

The above regulations are of comparatively recent date, and prior to their introduction a candidate wishing to be examined for a Third Engineer's certificate had to be over 21 years of age and had to have served an apprenticeship of at least three years' duration in an approved engineering works, during which time he must have been employed for not less than two years on the manufacture or repair of marine engines and for at least one year on the construction of marine steam engines. Only time served after attaining the age of 15 years was allowed to count. The candidate had also to have had one year's sea service in the engine room or stokehold of a ship with engines of or above 50 I.H.P., of which at least six months had to have been served as a fireman of such a steamship, only time served after attaining the age of 16 years being allowed to count. The candidate had also to produce evidence of satisfactory conduct and professional skill while serving in these capacities.

It may be seen, therefore, that until quite recently the Norwegian system of training marine engineers was almost identical with that of this country. The establishment of the engineers' schools, however, has resulted in a substantial reduction of the *statutory* period of workshop training.

Sweden.

There are three grades of engineers in the Swedish Merchant Navy, *viz.* chief engineers, second engineers and third engineers, for which certificates are issued to qualified candidates who succeed in passing the necessary examinations.

Third Engineers' certificates, however, are usually only sought by men employed in small coasting vessels, etc., and the examination for this grade is not compulsory for engineers who intend to obtain certificates as second engineers or chief engineers.

A candidate who wishes to be examined for a Third Engineer's certificate must be at least 19 years of age and possess the following qualifications:

He must have had at least 30 months' practical engineering experience ashore and afloat after attaining the age of sixteen, of which not less than four months must have been spent in a workshop where marine engines are made and repaired and at least 12 months must have been served in the engine room of a steamship carrying a certificated chief engineer or second engineer in charge of the machinery.

A candidate desirous of being examined for a Second Engineer's certificate of competency must hold the Swedish equivalent of the British School Leaving Certificate, failing which he must pass a preliminary qualifying examination in educational subjects (mathematics, Swedish language and geography). He must also possess the following professional qualifications:

Practical engineering experience ashore and afloat extending over a period of at least four years, including not less than two years in an approved engineering works, during which time he must have been employed for not less than 12 months on the manufacture of marine engines and have spent at least three months in a boiler shop. The candidate must also have not less than 20 months' sea service in the engine room of a steamship or motorship, of which at least six months must have been served in a steamship.

A candidate for a Chief Engineer's certificate must be the holder of a Second Engineer's certificate and must pass the qualifying examination, but before the Chief Engineer's certificate is issued to him he must serve for two years at sea in the Baltic or overseas trade in a steamship or motorship or ships having propelling machinery of not less than 500 I.H.P. and having a chief engineer or second engineer in charge of the engines.

A minimum of ten months must be served in each type of vessel. If less than ten months is served on board steamships or motorships, but the other requirements are complied with, a Chief Engineer's certificate will be issued but will only be valid for the type of vessel—*i.e.* steamships or motorships—in which the candidate has served the required time.

Sweden maintains five nautical academies for training deck and engineer officers, all controlled by the Government, and, under Swedish law, shipping companies are not permitted to employ officers without a diploma from one of these establishments.

It will be noted that the period of workshop training required for obtaining an engineer's certificate in Sweden is considerably shorter than in the United Kingdom.

U. S. A.

Certificated engineer officers in the U. S. Mercantile Marine are divided into four grades, *viz.* third, second and first assistant engineers and chief engineers. Certificates as such are obtainable by duly qualified candidates who succeed in passing the prescribed examinations.

A candidate who wishes to be examined for a Third Assistant Engineer's certificate must possess one of the following qualifications:

(1) Four years' service as a fireman in any steamship; or

(2) Three years' service as an oiler or water tender, or a total of three years' service in both these capacities, in any steamship; or

(3) Three years' service as third assistant engineer of steamships on the Great Lakes and all other lakes, Bay or Sound steam vessels, for a certificate as third assistant engineer in ships of corresponding tonnage; or

(4) One year's service as chief engineer or assistant engineer of river steamships, in addition to six months' sea service in the engine room of ocean-going or coastwise vessels; or

(5) He must be a graduate from the engineering class of a nautical school ship, with not less than two year's training in such engineering class; or

(6) He must have served an apprenticeship of not less than three years' duration in an engineering works, in the course of which he must have been employed on the construction or repair of marine, stationary or locomotive engines, in addition to which he must have at least one year's sea service in the engine room of ocean-going or coastwise vessels; or

(7) He must be a graduate in mechanical or electrical engineering of a duly recognized engineering college and have at least three months' sea service in the engine room of an ocean-going or coastwise vessel.

A candidate who wishes to be examined for a certificate as second assistant engineer must possess one or more of the following qualifications:

(1) One year's service as third assistant engineer; or

(2) Three year's service as second assistant engineer of steamships on the Great Lakes, etc., for a certificate as second assistant engineer in ships of corresponding tonnage; or

(3) Five years' sea service as an oiler or water tender in ocean-going or coastwise steamships; or

(4) He must have served an apprenticeship of not less than three years' duration in an engineering works and have been employed for at least one year as a journeyman in an engineering trade; or

(5) He must have served afloat as a junior third assistant engineer for at least two years while holding a Third Assistant Engineer's certificate; or

(6) He must be a graduate in mechanical or electrical engineering of a duly recognized engineering college and have at least one year's service in the engine room of ocean-going or coastwise vessels.

A candidate desirous of being examined for a certificate as a first assistant engineer, must possess one or more of the following qualifications:

(1) One year's service as second assistant engineer; or

(2) Three years' service as first assistant engineer of steamships on the Great Lakes, etc., for a certificate as first assistant engineer in ships of corresponding tonnage; or

(3) Two years' service as third assistant engineer of ocean-going or coastwise vessels while holding a Second Assistant Engineers' certificate; or

(4) Three years' sea service as an oiler, water tender or fireman in ocean-going or coastwise steamships; or

(5) Two years' sea service as a junior engineer in such vessels, while holding a certificate as second assistant engineer.

A candidate who wishes to be examined for a certificate as chief engineer must possess one or more of the following qualifications:

(1) One year's service as first assistant engineer of ocean-going or coastwise steamships; or

(2) Two years' service as second assistant engineer of such vessels, while holding a certificate as first assistant engineer; or

(3) Two years' service as a junior first assistant engineer of ocean-going or coastwise steamships while holding a certificate as first assistant engineer; or

(4) One year's service as an assistant engineer of such vessels for a certificate as chief engineer of any steamship of not more than 750 gross tons.

Certificates for service in motor vessels are issued under the same conditions as those for service in steamships, but any holder of a steam certificate may be examined for a motor certificate of the same grade after three months' service in a motorship in a capacity one grade lower.

The wording of these regulations appears to be ambiguous and makes it difficult to compare the U. S. certificates with the British ones; generally speaking, however, the Assistant Engineers' certificate (all three grades) are comparable with the British Second Engineers' certificate, and the American Chief Engineer's certificate with the British Chief Engineer's certificate, although the requisite professional qualifications for the latter grade are by no means comparable.

A peculiar feature of the U. S. regulations is the fact that a candidate wishing to be examined for a certificate as a second or first assistant engineer need not necessarily possess a certificate for a lower grade, and that any ship's fireman with the requisite sea service is eligible to present himself for examination for a Second Assistant Engineer's certificate; having obtained this and spent another year at sea as an assistant engineer, *i.e.* as a junior engineer, he becomes eligible for examination for a certificate as chief engineer of a small ship of up to 750 gross tons. In these circumstances the significance of the statement appearing in the U. S. Maritime Commission's Report to Congress on training Merchant Marine Personnel to the effect that about 80 per cent of all American merchant service officers (deck and engineer) have received no systematic training, becomes apparent.

About 200 cadets are graduated annually from the four State nautical schools and of these a small proportion go to sea as assistant engineers, but except for these, the majority of American marine engineers come from Great Lakes ships, the U. S. Navy and Coast Guard services, or begin their careers in a subordinate capacity in the stokehold or engine room.

Under a new system of recruitment and training adopted by the U. S. Maritime Commission in 1938, selected holders of certificates as third assistant engineers between the ages of 19 and 25 became eligible for appointment as cadet officers, in which capacity they underwent about 12 months' special training on board one of the Commission's vessels in the service of one or other of the leading shipping companies. During this period of training they had the status of junior officers and received pay at the rate of $75 per month.

The new system of entry and training of engineer cadets for the U. S. Maritime Commission's fleet adopted in 1939 was the outcome of a very thorough survey of all the systems of training employed in the leading maritime countries of the world, which was summarized in the Commission's Report to Congress dated 1st January, 1939. Applicants for entry must be between the ages of 17 and 25 and pass a qualifying examination conducted in every Congressional district in the U. S. at regular intervals. The names of successful candidates are placed on an "eligible list" in the order of national competitive standing, from which they are appointed as cadets in the deck or engineer departments and undergo a period of four years' intensive training ashore and afloat before being examined for certificates as third mates or third assistant engineers.

After appointment cadets receive one year's general training at sea, at the end of which they must pass a progress examination. Those who are successful are then given 12 months' intensive training ashore in one of the Commission's training establishments. During this period engineer cadets are instructed in advanced mathematics, applied dynamics, applied physics, electricity and workshop practice. Cadets who succeed in passing the prescribed examination at the end of their year of shore training then go to sea for two years' further training in the Maritime Commission's passenger and cargo vessels. During the first six months they work with the wipers, the second six months are spent in the stokehold, then come three months of engine-room watchkeeping and work with the oilers, three months' duty with the electrician, three months with the storekeeper,

plumber and deck machinist (donkeyman), and finally three months' engine-room watchkeeping with the engineer officers of the ship. A very detailed course of study of marine engineering subjects is prescribed by the Commission and the cadets are required to keep notebooks which are inspected periodically by representatives of the supervisor of cadet training. Examinations given to cadets by these officers and the engineer officers of the ship are written in these books, and their progress is carefully watched at all times.

After completing four years' training ashore and afloat, cadets take the examination for the Third Assistant Engineer's certificate and after obtaining the latter continue at sea in the ordinary way. Cadets of outstanding ability, however, are given six months' additional training in a shipyard having an engineering school attached to it.

The Commission maintain a number of training ships for Merchant Service personnel, including newly-entered cadets. One of these vessels, the "American Seaman," has accommodation for 225 trainees.

Throughout the whole of their training period ashore and afloat, cadets receive pay at the minimum rate of $50 per month and all found. They are also entitled to various allowances.

While serving afloat cadets are regarded as members of the crew and are employed as such, but they mess with the officers.

The new system of training has not been in force long enough to produce practical results, but the standard of general and technical education of the new entries is reported to be extremely high—doubtless owing to the severe competition among would-be candidates induced by present-day conditions in America.

A proper appreciation of the merits of this system of cadet training will probably not be possible for some years to come, in addition to which present-day circumstances and the rapid expansion of the U. S. Mercantile Marine under the auspices of the Maritime Commission may necessitate a curtailment of the training period of the engineer cadets.

In dealing with the regulations governing the entry and advancement of marine engineers in the countries enumerated above, specific reference has not always been made to the provision existing in every country for the issue of certificates to junior commissioned officers and warrant officers belonging to the engineer branch of the navy of the nation concerned. Such transfers of ex-naval engineer officers to the Merchant Navy are almost unknown in this country, but are common enough in certain foreign states, notably in France, Italy and Japan. Similarly, quite a number of Mercantile Marine engineers obtain permanent commissions in the navies of these countries after completing their statutory period of naval service under the conscription laws of the country concerned. Such transfers to the naval service are not to be confused with service in the naval reserve.

A comparison of the various systems of training in force in the nine countries reviewed above, appears to indicate that they can be divided into two main groups. Germany and the Scandinavian countries retain the principle of the direct entry of candidates who have had some workshop training and—in some cases—a small amount of sea experience, but provide special training schools or courses of instruction which junior engineers who have completed a prescribed period of sea service must attend before they can become eligible to take the examination for advancement to a higher grade. France, Italy, Japan and the Netherlands, on the other hand, maintain special engineering colleges for the theoretical and practical instruction of students entered from secondary or technical schools, the period of college training being supplemented by a more or less prolonged term of service afloat before taking the examination for advancement to one of the junior grades of engineer officer. The scheme for the entry and training of

engineers adopted by the U. S. Maritime Commission might be described as a combination of both the above systems.

It is clear that the *minimum* time required to train a young man as a marine engineer is five years, even when he has undergone some preliminary workshop training before being entered as an engineer student, cadet or apprentice. The workshop training provided for the latter before they are sent to sea might strike most British marine engineers as somewhat inadequate, but it appears to meet the requirements of the responsible authorities in the various countries under discussion. Much depends, of course, on the nature of the practical workshop instruction provided. It has often been said that an apprentice serving five years in an engineering works spends most of the first two years performing the functions of a laborer's boy in the shops, although a stricture of this nature is by no means generally applicable to the junior apprentices in all the shipyards and engineering works in this country.

Another outstanding feature of most of the foreign systems of entry and training is the relatively high standard of general education required of candidates for admission to the various technical training establishments, whereas one of the most serious disadvantages of the engineering apprenticeship system in this country is that the age of entry rarely makes it possible for a boy to possess more than the equivalent of a primary school education. The vital importance of a sound general education as a basis for the study of the technical, mathematical and scientific aspects of modern marine engineering scarcely needs stressing, but until the sea-going engineer acquires the same status as his brethren in the civil, electrical or mining branches of the profession, his calling is unlikely to appeal to the average boy of good education.

A matter closely bound up with the entry and training of marine engineers is their subsequent advancement. The grading of engineers in the British Mercantile Marine compares unfavorably with that in most foreign merchant services (with the notable exception of that of Germany). Although the standard of professional knowledge expected from candidates presenting themselves for examination for Second and Chief Engineers' certificates is quite as high as that of the corresponding examinations in any foreign merchant navy, the possession of these certificates counts for far less in this country than abroad, and all the senior engineer officers of a British ship of even moderately large tonnage are expected to hold Chief Engineer's certificates. The informal system of grading adopted by the shipping Federation whereby officers in passenger liners rank senior to those in cargo liners, while the latter are, in their turn, senior to those in tramp ships, etc., is not altogether satisfactory, as it was evolved for another purpose, *viz.* that of providing a basis for determining scales of pay. Attention has been drawn to the wider system of grading which prevails in several foreign merchant navies—*e.g.* those of Japan and the United States—in which at least four certificated grades for engineers are provided for, in addition to those reserved for engineers of coasting vessels and other small craft. Suggestions have been made regarding the advisability of introducing an intermediate certificate—such as a First Engineer's certificate—into the British Mercantile Marine, in order to facilitate the application of a system of grading based on seniority reckoned in years of sea service while holding any particular certificate. It is generally agreed that the regulations governing the award of an Extra-Chief Engineer's certificate should not be affected by any such change in the present system of grading.

The introduction of an uncertified grade of assistant engineer has also been proposed. This designation might, perhaps, be utilized for senior engineer students, cadets or apprentices undergoing a period of training afloat

in the event of the adoption by this country of a system of entry and training on the lines of those favored by other maritime nations.

It must not be forgotten, however, that the institution of additional certificated grades may mean the introduction of more examinations for advancement to these, and that there are many marine engineers who would view additions to the present-day professional examinations with the utmost distaste. In this connection, the system adopted in the Mercantile Marine of Japan, whereby graduates of the nautical colleges who obtain satisfactory reports concerning their professional abilities and conduct during their qualifying sea service are not required to pass any examinations for advancement to higher grades, might be worth considering.

The adoption of a system of grading based on seniority with a view to the application of a "national scale" of pay for all Mercantile Marine officers has many advocates in this country and may have much to commend it, although most of the leading British shipping companies already have standard scales of pay for service in various types of vessels and in different parts of the world. The adoption of the Burnham Scale for the scholastic profession was hailed with great satisfaction by the latter on its first introduction, but has since proved something of a mixed blessing to many of its senior members when in search of employment. It must be borne in mind that the total amount of the pay roll of any ship or establishment is usually governed by considerations which do not take account of progressive increments of salary regardless of expenditure involved.

Any revised scheme for the entry and training of Mercantile Marine engineers will, as a matter of course, have to pay due regard to the requirements of national defense. The importance of this aspect of the problem has inspired some would-be reformers to put forward various schemes for a post-war reorganization of the British Merchant Navy which involve changes of a revolutionary character. These include the nationalization of the Mercantile Marine and the militarization of its personnel, but it would obviously be injudicious to draw up any new scheme for the entry and training of marine engineers which was based on the assumption that they are likely to take place. The functions of the Mercantile Marine are of such vital importance to this country that it would be a fallacy to regard Merchant Navy personnel as potential reserves for the Royal Navy, although it is clear that the Mercantile Marine must always be prepared to supply large numbers of ships, officers and men for the naval, transport and similar services in time of war. Any scheme of voluntary naval training for Mercantile Marine engineers for the purpose of granting them commissions in the Royal Naval Reserve, has one serious drawback—it means the calling-up on mobilization of many engineers who occupy positions of responsibility ashore and afloat from which they cannot be spared in time of war or of national emergency without detriment to the work on which they happen to be employed. In such circumstances, it is clear that *either* their work—which may be of national importance—will suffer if they are called up *or* that the Royal Navy will be deprived of the services of a qualified engineer officer at a time when it is in urgent need of them.

Bearing these considerations in mind, it must be admitted that the Japanese system which provides for a minimum period of six months' naval training for *all* engineer students, appears to overcome the difficulty. Any new scheme for the entry and training of marine engineers in the United Kingdom could equally well make provision for a period of naval training in one of the mechanical training establishments of the Royal Navy, which *every* engineer student, cadet or apprentice would be required to undergo. The technical naval training of a Mercantile Marine engineer differs from the military or air force training which the civil, electrical, mechanical or

mining engineer ashore might elect to undergo, in that it constitutes an asset to the vocational training of the former, whereas in the case of the latter it is merely an interlude. If every marine engineer ashore or afloat were a member of the Royal Naval Reserve, many of the difficulties connected with the manning of warships and naval auxiliaries on mobilization would be simplified and there would, at the same time, be less likelihood of trouble over the calling up of engineer officers of the R.N.R. who might be employed on work of national importance.

Although it is generally agreed that a revised system of entry and training of marine engineers is called for in this country, there might be no need to depart from the existing Board of Trade (or Ministry of War Transport) regulations in regard to the qualifications laid down for candidates desirous of being examined for Second Engineer's certificates. The present four years' workshop experience (or three years at an approved technical school with two years' workshop training) together with 18 months' sea experience, prescribed for such candidates, does not differ to any great extent from the total period of training undergone by young marine engineers in America or Japan. It would therefore appear that little, if any, change would be required in the regulations to enable a revised system of entry and training to be introduced.

Furthermore, any new system of entry and training should, in the first instance, be used to *supplement* the existing arrangements rather than to *replace* them. Several years of experience in the working of any new system would obviously be necessary before a final decision as to its merits could be arrived at, and suitable provision should be made at the time of its first adoption for subsequent modifications in its application to obtain the best results.

Provision would also have to be made for additional technical instruction to be available for such marine engineers entered under the present system who might wish to take advantage of it, and the special claims of the young engineers who have joined the Merchant Navy without any previous experience of marine engineering during the present war should not be overlooked, as some of them may wish to continue at sea after the war and it is precisely these men who are likely to prove efficient sea-going engineers.

THERMAL STRESSES AND SHRINKAGE IN WELDED SHIP CONSTRUCTION.

The report of a Subcommittee of the Committee on Welding in Marine Construction is reprinted below from the *Welding Journal* for September 1941. The Subcommittee, appointed in 1935 from the Membership of the American Welding Society, included H. W. Pierce as Chairman, D. Arnott, A. G. Bissell, C. W. Bryan, R. H. Cunningham, E. D. Debes, and T. M. Jackson as Members.

I—Introduction.

In the field of naval ship construction, the Bureau of Ships has developed, during the past five years, detailed specifications covering the applications of welding, particularly in regard to the procedure to care for the effects of thermal stresses and shrinkage. In merchant ship construction, the regulatory bodies have, speaking generally, been much less specific in regard to this phase in their written rules and specifications, dealing in the results to be obtained rather than in specific methods of procedure. A question of

primary importance is, therefore, the necessity for more or less elaborate precautions to prevent or mitigate possible adverse effects of welding shrinkage. If such steps are not required or may be simplified, naval construction will benefit by the elimination of much costly procedure coupled with a reduction in time of building welded ships. Ship welding has had extensive service trial over a period of years with a truly remarkable record of satisfactory performance. More will be said of the matter of service failures later in this report but it may be stated that many ships whose construction in whole or in part violated many principles of stress-free welding procedure have undergone extraordinary sea tests without failure. It is therefore pertinent to reexamine the theory and logic of some of these principles if for no other reason than to account for this excellent record.

The general topic of thermal stresses and shrinkage resolves itself into three main sub-divisons:

I. The loss of original dimensions of welded parts or assemblies, which is reflected in the loss of the principal design dimensions of the ship if no allowance is made.

II. Distortion or the loss of shape of individual parts or assemblies. This includes warping and twist, the appearance of buckles and wrinkles in plane surfaces, or the rise of bow or stern.

III. Residual or "locked-up" stresses, either in the welded joint or in the structure due to shrinkage in proximity to the welded joint.

II—Loss of Dimension.

The most obvious result in welded construction, which does not occur at all or only to an inappreciable degree in other forms of jointing, is loss of dimension due to shrinkage. Further, this loss of dimension is encountered in two different forms. When a joint is made between two individual parts, there is shrinkage of the filler metal, added in the molten state, which tends to draw these parts together. If one part is being attached to the other, that is, when a weld is made to a continuous or passing member, there is also shrinkage in the vicinity of the weld which is reflected in the shortening of the passing member. Applied to ship structure, these two forms can be represented by (*a*), butts or seams in shell plating, and (*b*), the attachment of framing to the shell plating. Unless compensation is made for both forms, the completed shell will be less than its original designed length.

The Subcommittee has collected a great deal of test data as well as records of measurement on full size or actual ship structures. In addition, a very considerable amount of data has been published and a notable collection or summary of these data is available in an A.W.S. Research Supplement.[1] Analysis of all this information reveals so wide a discrepancy in shrinkage between similar joints as to render a summary or tables of predicted shrinkage valueless. The data on record also show wide differences between small and large-scale tests. It must be concluded that too many variables enter this phase of the problem, many beyond the control of the welding operator or shipbuilder.

The problem of dimension is not, however, of primary importance. Where no correction has been made, shrinkage in the length as high as 6 inches in vessels less than 150 feet long has been reported. Such loss is actually of little moment in so far as speed and power are concerned

[1] "Shrinkage Distortion in Welding," by W. Spraragen and G. E. Claussen, American Welding Society Journal, Research Supplement, July, 1937.

and generally is of concern only in the loss of capacity. In the construction of larger ships, some means of correction has invariably been employed so that the loss in dimension has generally been insignificant.

Among the corrective measures which have been employed in ship construction are (1) the use of expanded scales, (2) the use of excess length or allowance over mold loft or drawing dimension, and (3) "lift from ship" correction.

The use of the expanded scale is borrowed from the pattern shop and foundry. Since a finished casting is smaller than the pattern molded in the sand, an expanded measuring stick is used in the construction of the pattern which makes allowance for the shrinkage per foot of the particular metal being used. The application of this method to a welded ship assumes that welding shrinkage, like that in the casting, is relatively uniform throughout. Unfortunately, this is rarely if ever true. Not only are we faced with wide variations in shrinkage of similar joints as noted above, but there are also wide differences in the application and amount of welding in many different parts of the structure. A deck, for example, may be transversely framed whereas the shell plating in the vicinity of that deck may be largely longitudinally framed. One may consist of considerably heavier plating than the other although the attachment of framing may be made with welds of similar or identical size since the strength of the connection desired is not necessarily a function of plate thickness. It is obvious that the same expanded scales cannot be applied to both structures. Furthermore, in shipbuilding, the use of scales, and the measuring and setting of various parts, is not restricted to any one operation or department. Correlating the proper scales with regard to varying ship structure throughout the progress of material from storage yard to ways has generally proved too complicated a problem for the benefits derived and, although actually tried in practice, this method of correction, as far as the Subcommittee is aware, is generally no longer in use.

A method in common use is to add an arbitrary allowance or excess to the length and width of parts subject to welding shrinkage. As a general rule this allowance is considerably more than the shrinkage actually expected and the excess is then removed after as much shrinkage as possible has taken place. Only where it is impossible to leave such excess is it wise to allow the exact shrinkage predicted. The excess or allowance method may be made on all parts and ships' dimensions corrected at intervals, thus allowing a considerable amount of material to be used without flame cutting or chipping in erection.

A third corrective measure is to leave selected parts of the structure to be measured or "lifted" from the ship after adjacent structures are completely welded and shrunk to the final dimension.

III—Distortion.

Distortion, particularly when localized in the form of buckles in flat or but slightly curved plates, is an especially troublesome problem to the shipbuilder. While it may be frequently argued that such distortion has little or no effect on the strength or service life of the ship, the unsightliness of such distortion coupled with the complication in the attachment of other parts to warped structure creates a major problem. Where excessive distortion occurs and is unacceptable, the warped part is straightened by the application of heat or mechanical work, usually at great expense. In ships with light scantlings, the cost of straightening has frequently exceeded the cost of fitting and welding the structure. Viewed from the angle of cost, appearance, or utility, prevention of distortion is so much to be preferred to its correction that an extensive study of this particular problem is warranted.

In the field of preventive measures, shipbuilders have experimented with all manner of methods, the principal ones of which may be classified as follows:

(*a*) *Pre-springing or initial distortion*—In its simplest application, this method consists of mechanically setting or bending a part in an opposite direction to which warpage is expected so that the effect of welding is to restore the part to its desired shape.

(*b*) *Strong-backs or jig methods*—The size and variation of ship structures generally preclude the use of jigs of the type frequently applied to small machine or sheet metal assemblies. A variation which is applicable to large structures is the use of strong-backs and temporary stiffening by which the structure is given increased resistance to distortion but which are removed after the welding has been completed and cooled.

(*c*) *Drum-heading*—This classification refers to a method frequently used on large areas where the boundaries have a large degree of permanent or temporary restraint. The effect of the welding operations on this plating tends to shrink it in size and, as a result of the boundary restraint, the plating is kept flat.

(*d*) *Extent of tacking, and wandering sequence*—This method is a variation of the drum-head or restraint method. If a considerable section of structure is heavily tacked or if a wandering sequence is employed which involves the virtually simultaneous completion of all welded connections, as opposed to successive completion frame by frame, there may be a considerable reduction in distortion due in part to restraint and part to reduction in local heating.

(*e*) *Design*—The importance of design in reducing distortion cannot be over-emphasized. In this classification falls the use of a minimum amount of filler metal, suitable arrangement of joints to avoid localized areas of extensive shrinkage, elimination of shift of butts in all-welded construction, etc. It is not always possible, however, for the designer to obtain such ideal conditions, since many basic specifications require modification and, further, a large proportion of ship draftsmen have not yet had an opportunity to familiarize themselves with the effect of welding shrinkage.

Corrective measures can be roughly classified as follows:

(*a*) *Shrinkage*—While varying in detail, this method consists of alternative heating and cooling, frequently accompanied by hammering or mechanical work, thus shrinking excess material in a wrinkle or buckle.

(*b*) *Shrink welding*—This is a variation of (*a*) above, in which the heat is supplied by running beads of weld metal on the convex side of a buckled area. On cooling, the combined shrinkage of the heated parent metal and the added weld metal removes the distortion. The beads of weld metal may then be ground off if a smooth surface is desired.

(*c*) *Added stiffening*—This method, which is applicable only to plate panels, consists of pulling the plate into line by strong-backs and welding additional stiffening to the plate to make it retain its plane. In addition to the stiffness added, there is also benefit from shrinkage in the connecting welds.

It is important to note that certain of the preventive measures, notably drum-heading, extensive tacking, and the wandering sequence as well as the corrective methods of torch shrinking and shrink welding, are directly opposed to the theory that the structure should be free of residual stresses. The success of these measures is due to the fact that opposed and equal stresses are set up. Taken rather broadly, structures tend to relieve themselves by distortion. It follows that its prevention, or correction, means the creation of residual stresses in many instances.

IV—Residual or "Locked-up" Stress.

Welding procedure, by which is generally meant the sequence of operations in regard to both erection and welding, has been referred to above in connection with the control of shrinkage and distortion. It also has been closely studied and developed for two other purposes: first, to assure completion of a weld without total or partial failure, i.e. cracking; and second, to leave structures not adaptable to furnace stress relief in a satisfactory condition for service.

The satisfactory behavior of welded structures in service is predicated upon sound welds. The obtaining of sound and properly-fused welds, free of checks and incipient cracks, as well as slag, porosity, blow-holes, and the like, is therefore of major importance. To this end procedure includes much more than sequence of welding; in fact, other factors such as preheat, the continuity of the welding operation, peening, and an endeavor to assure a uniform distribution of stress over the joint are often of equal importance.

Procedure also shares importance with other factors in this matter of obtaining sound welds, namely, adequate inspection, suitable equipment, the proper training and qualification of operators, and not least important, the accessibility of the joint. Even the most carefully developed procedure cannot be depended upon to compensate for deficiencies in the other requisites for sound welds.

The reduction or elimination of residual stresses in the completed structure by means of a definite procedure intended to permit unrestrained shrinkage is the point which is generally given primary importance and on which there are, perhaps, the widest divergence of opinion and elements of controversy. Ship structures generally, with the exception of individual weldments for stern posts, etc., must be placed in service in the as-welded condition. The effect of residual or locked-up stress and the necessity, if any, for its consideration are therefore of primary importance and have received major consideration by the Subcommittee.

"Stress-free" procedure methods, which were referred to at the beginning of this report, are based on two fundamental assumptions:

(1) That residual or locked-up stresses can be avoided or minimized by a welding procedure in which no positive external restraint prevents free shrinkage.

(2) That these residual stresses are always detrimental and should be avoided at all costs.

Discussing these assumptions in order:

There has been a considerable volume of test data published in recent years on shrinkage stresses in the vicinity of welded joints of various types. Examination of these reports leads to the conclusion that the stress distribution in and near a welded joint is exceedingly complicated and indeterminate. Due to the nature of the process, involving high temperatures, there is plastic flow as well as elastic movement in adjacent parent metal. Time and temperature relations are affected by a large number of variables, some completely beyond the control of the operator, and others which vary widely with different operators. In most shipwelding processes, the filler metal is added literally drop by drop with that first deposited cooling more or less rapidly. Even in the highest speed automatic processes, with the possible exception of flash welding which is not applicable to ship joints in general, a large part of any welded joint has time to cool before completion of that joint and obviously supplies a high degree of restraint. Therefore, we may expect to find, as reliable investigations substantiate, the fact that high residual stresses exist irrespective of any external restraint.

The addition of external restraint may or may not increase the stresses in and near the joint. The lack of restraint probably prevents stressing the member generally, i.e., at a distance from the welded joint. If, however, stresses well beyond the yield point, resulting in permanent set exist in or adjacent to the welded joint, it appears illogical to employ elaborate means to reduce elastic stresses at points between welds.

The second assumption, namely, that residual stresses are always detrimental and should be avoided at all costs, may also be seriously questioned both in theory and from a practical standpoint. Residual stresses compose an internal force system which obviously must be in equilibrium. When such a system is subjected to externally applied loads, there is no simple addition to like forces from which to conclude that some local point may be overstressed. For example, externally applied loading in tension cannot be additive to residual stresses of like sign until the balancing compressive stresses of the system in equilibrium are overcome. This principle is well established as in the case of pre-loaded bolts in cylinder head joints and has been demonstrated in a variety of test devices.

A rolled shape, as delivered from the steel mill, is in a similar state of locked-up stress. Investigators have measured residual stresses up to the yield point existing in rolled sections.[2] An indication of these stresses is the warpage of an I-beam when the web is split to form two T-sections, yet these beams are used safely under the assumptions of our beam formulas.

A further consideration which reduces the importance of residual stresses is the property of shipbuilding steels, all of relatively high ductility, to elongate under stress. Although the yield point is reached in comparatively slight extension, considerable elongation is required before such steels reach the point of failure. Before local points reach any appreciable part of this elongation the load has been re-distributed with adjacent material assuming a larger proportion. This principle has been used for years in the "stretcher-leveling" of steel plates. In this method, the tendency of a plate to buckle and warp after rolling due to residual rolling stresses is removed by stretching the plate beyond its original elastic limit, thus re-distributing the stresses in a more uniform manner.

There is considerable evidence that residual stresses, whether induced by cold work such as rolling, bending, or flanging, or by hot work, either welding or shrinking, tend to distribute themselves and to reduce peak values particularly when subjected to external loading. I-beams which have been allowed to season do not warp on splitting to the same degree as beams used on receipt from the mill. Castings are frequently allowed to season, at ordinary temperatures, for the same reason. Stress-relieving by furnace treatment is in part an accelerated seasoning process. The critical time, therefore, in a welded structure is a period of somewhat indeterminate length beginning immediately after the welded joint is made. If exposed to sudden changes of temperature which induce highly localized stress before reasonable seasoning can take place, there is the possibility of failure. There have been few such cases in shipbuilding; nevertheless, they are not unknown and appear to account for the majority of plate or joint failures particularly during the winter months in northern yards.

A ship can be regarded, due to its water-tight compartmentation, as a series of tanks or pressure vessels. So regarded, however, it would be classed as a thin-walled pressure vessel. In pressure vessel practice, it is well established that the necessity for stress relieving and the avoidance of cumulative residual stress of a probable biaxial nature, is a function of relative wall thickness compared to tank dimension. These ratios in a ship

[2] "Determination of Initial Stresses," Josef Mathar, A.S.M.E. Transactions, 1934; also A.W.S. Journal, July, 1934.

are so low that, by pressure vessel standards, stress relief is wholly unnecessary except in a few heavy weldments forming such items as stern post, rudder post, etc.

The Subcommittee believes that it is impracticable to set a limit on thickness of plating in which the presence of residual stresses is of minor importance. Experience in welded ships indicates that plates up to 1 inch thick may be welded successfully although restrained from free shrinkage. The rigidity of a structure, however, depends not only upon the thickness of plating, but on the relative degree or stiffening, the size and relative dimensions of unsupported panels, and many other factors which make generalization impossible.

From the purely practical standpoint, it may be pointed out that welded joints in large, and frequently complicated ship structures, can rarely be made under conditions which permit the uniformity of shrinkage, irrespective of any external restraint, that has been so frequently assumed. It can also be stated that such structures cannot be erected, regulated, and prepared for welding without an indeterminate degree of restraint. Regardless of the methods employed, it is a matter of practical experience that few structures approach the degree of freedom assumed in theoretical discussions of "stress-free" procedure. To avoid excessive distortion and subsequent straightening, considerable use is made of the step-back, extensive wandering, and berth systems of welding. It cannot be argued that these procedures, especially the latter two, permit the freedom of relative shrinkage which is assumed. The use of tack welding and bolting, as actually carried out in practical shipbuilding also denies such freedom of relative movement.

Mention has been made of the use of shrinkage methods to correct distorted structure. It appears highly illogical to take elaborate precautions to prevent or reduce residual stresses only to employ means in fairing the finished structure which depend for their effectiveness upon setting up residual stress.

It is likewise a matter of practical impossibility to complete all operations of welding large structures in perfect sequence. In new construction there are frequent closing or final joints which can be made only after previous work has reduced or entirely eliminated freedom to shrink. Moreover, in repair work as well as in major alterations to existing ships, it is impossible to avoid "locked-up" conditions. The vast number of these jobs, ranging from the replacement of a damaged shell plate to the extensive rebuilding of a ship, which have been accomplished over the past fifteen years and which have successfully stood up under all manner of service conditions is ample evidence that we depend not upon the elimination of residual stresses but upon the ability of the material to accommodate such stresses.

The considerations discussed in the foregoing have been based upon (*a*), service experience and observation, (*b*), reference to laboratory and test work by various investigators as published in the technical literature, and (*c*), tests and experiments made by individual shipyards in the course of their work. Much can be learned from the analysis of failures, perhaps even more than from wholly successful operations. In this phase of its work, however, the Subcommittee has encountered the usual difficulty in that failure of any structure involves the interests of so many individuals or groups that it is rarely possible to make an unbiased analysis of cause and effect, particularly for publication. So far as the Subcommittee is aware, service failures of ship structure in which welding shrinkage has played a possible part have been rare and, in comparison to the extent of work accomplished, insignificant. It is regrettable, nevertheless, that these instances, which might clarify much misunderstanding, have not or cannot be made available for unprejudiced analysis.

Shipbuilders in recent years have demonstrated that the welded ship suffers but little handicap in building cost or time where the structure is not complicated, or where the step by step, stress-free procedure is not rigorously applied. The importance of a reasonable and logical viewpoint toward residual stresses lies in removing these handicaps, so generally claimed in naval vessels and in more complicated type of merchant ship.

V—Conclusions.

The Subcommittee, as individuals, concur in the following:

1. That the phenomenon of shrinkage is complicated by so many factors beyond the control of the shipbulider that tables of predicted shrinkage are of no value.
2. That the detrimental effects of correcting distortion subsequent to the completion of the structure may be as serious as the residual stresses involved in most methods of prevention.
3. That residual stresses in ships, incident to joints welded under various and indeterminate degrees of restraint, do not appear to affect the strength of the structure in service provided:

(*a*) The filler metal is deposited by electrodes conforming to Grade E6010 of the filler metal specifications or equivalent process giving a similar degree of ductility.
(*b*) The structural material is of proved welding quality.
(*c*) Due care and diligence is observed in preventing, or detecting, stress cracks during and immediately following the welding operation.

VI—Appendix.

The Subcommittee acknowledges with thanks the many comments and suggestions received from the membership of the Society's Technical Committees. Of these, possibly the most pertinent is the criticism that conclusion 3 (*b*) is not fully defined. So far as the Subcommittee is aware, welding quality has not been accurately or fully defined by any competent authority. A great deal of work has been done and a great deal of material has been published on this subject. In so far as ship construction is concerned, experience indicates that the steels in common use are of welding quality within the meaning of the Subcommittee's conclusions.

Since the comment of Professor Mortimer F. Sayre, of Union College, Schenectady, New York, has direct bearing on this matter of welding quality as well as upon other conclusions of the report, it is given below:

"Probably wisely, the report emphasizes the conditions under which residual stresses are not dangerous, rather than those under which they are dangerous. The reverse side of the picture could possibly tentatively be pictured as follows—and I offer this statement partly in order to elicit criticism with view to modification:

"In absence of defective workmanship residual stresses whether due to thermal or other causes become dangerous only if:

1. The material is brittle, with high resistance to plastic flow as compared to its resistance to cohesive failure.
2. The material is in a notch sensitive state, possibly measurable by unduly low notch impact value.
3. The piece is so thick and so rigid that it maintains its shape even after very high internal stresses have developed. This rigidity prevents plastic flow from occurring, sufficient to relieve these stresses.
4. The stress distribution is such that localized areas of three-dimensional tensile stress can be developed. At these points shearing stress is absent

or negligible in amount, and so plastic flow with resulting relief from excessive stress does not occur.

5. Fatigue failures may occur in structures at points of alternating stress. Evidence seems to suggest, however, that in absence of the stress conditions noted in (3) and (4) above, failure will be due to the presence of stress raisers rather than to the presence of initial stresses."

SIDE LAUNCHING OF SUBMARINES.

First read before the Shipbuilding Section of the Swedish Technical Society in November, 1940, J. Ljunggren's paper was published in Teknisk Tidskrift, April 19, 1941. Subsequently translated, it appeared in the September 26, 1941, issue of Engineering (London). It is here reprinted from the latter publication.

In Sweden, most shipbuilding berths are arranged so that the vessels may be launched endwise on one or two sliding ways. This method of launching necessitates, among other things, access to sufficiently wide and deep water outside the berth for the ship to be able to run off the slip for its whole length, with a certain margin, in addition, for safety. At the end of 1939 the Kockums Verkstad works was faced with the problem of building new berths, in a period of about two months, for the construction of submarines, which had to be finished in a comparatively short time. There was no room in the yard for berths with the traditional lengthwise position, and, even if there had been, it would have taken too long to get the berths ready. A scheme was then put forward to use for these submarine berths an area along the yard canal, which is, however, only about 37 meters wide, necessitating sideways launching.

This method had not been previously used in Sweden, and it was generally considered a risky step when the management of the yard decided upon this method of launching submarines; particularly as, in view of the proportions of the site, the construction of the berths had to be different from known precedents; for example, in the American yards on the Great Lakes, where slipways for side launching are familiar. The berths and launching arrangements which have been developed at the Kockums works are described below. A section of the building site before the construction is shown in Figure 1, herewith.

If the inclination of the launching ways of 1 in 8 to 1 in 12, customary in the American yards, had been adopted, the berths would have had to be built as shown in Figure 2, with the disadvantage of having to carry the railway siding on removable beams. Eventually a layout was chosen as in Figure 3, also on this page, the launching ways being given the extremely steep slope of 1 in 4, thus causing the minimum encroachment on the canal and the railway siding. Figure 4 shows a plan of the area, with concrete platforms for the simultaneous construction of two submarines. Both berths were served by a single Diesel-engined crane.

There is nothing to prevent more than two parallel berths being constructed, using the same launching ways. In this way, either all the vessels can be launched at approximately the same time or, as soon as one boat is launched, the other boats under construction can be shifted one stage nearer to the slipway and a new vessel begun at the berth farthest from the water. This naturally has certain disadvantages which specially affect submarines, but these were fully overcome. The construction of the sloping launching ways is shown in Figures 5, 6 and 7.

CONDENSED REVIEW OF SOME RECENTLY DEVELOPED MATERIALS.

Reprinted from Machinery, October, 1941, this review describes the properties and applications of many new materials. The tables are arranged alphabetically by trade names.

Class of Material	Trade Name	Properties	Applications
Refractory Ceramic Material	Alsimag 222	Machinable, ceramic material with low dielectric loss at high frequencies which can be used at temperatures up to 2500 degrees F. Available in round or tubular form and in disks or plates; special shapes also can be supplied. Because of abrasive nature, must be machined with carbide tipped tools.	Especially suitable for building working models. Also suitable for application in electronic field.
Protective Coating	Amercoat	A liquid plastic coating for brushing or spraying on metal or concrete surfaces. It is odorless, tasteless, and chemically inert. Will not check, crack, or fracture when subjected to vibration, and also resists abrasion. Usually applied in three coats.	Suitable for use where resistance to salt water, cold mineral acids, alkalies, oils, fats, gasoline, mineral salts, and alcohol is required. Not suitable for use when subjected to certain acids in concentrated form, aldehydes, benzine, carbon disulphide, and ether.
Malleable Iron	Belectromal	A malleable iron which has high strength without sacrificing the ductility and machinability usually associated with this type of iron.	Intended for parts requiring greater strength than ordinary malleable iron, but having comparable ability to withstand shock and to machine readily.
Bearing Babbitt	Bermax	An improved high-lead babbitt that is not subject to oil corrosion. It has a melting point slightly higher than that of tin-base bearing alloys, and can be cast by any method without fear of segregation. Maximum permissible unit pressure, 1800 pounds per square inch.	Particularly recommended for rebabbitting steel-back or bronze-back bearings or housings of cast steel or cast bronze. Suitable for a wide range of applications in the automotive, Diesel engine pump, and compressor fields.
High-temperature Lubricant	Caloria	A high-temperature lubricant that gradually vaporizes when used, and leaves no residue. Also available with small amounts of colloidal graphite added.	For use wherever difficulties are experienced with high-temperature lubrication, due to deposits of carbon and "varnish" remaining after evaporation of the lubricant.
Bearing Material	Carobronze	A bearing material having ability to carry heavy loads at high speeds. Contains 91.3 per cent copper; 8.5 per cent tin; and 0.2 per cent phosphorus.	It is available in tubular form, wire, rods, and bars, and sheet and strip. Shorter, thinner-walled bushings are made possible by this material.
Welding Alloys	Castolin	A series of eutectic welding alloys that, because of their low melting point, afford rapidity of operation, freedom from warpage due to high temperatures, and protection against detrimental structural changes in the base metal. The eutectic alloy rod melts and fuses with the base metal, which is heated but not molten, the bond being accomplished by capillary action.	Applicable for joining a wide range of metals; for low-temperature color-matching welds on cast iron; welding of delicate and intricate castings; low-temperature brazing of steel, malleable cast iron, tungsten carbide, and aluminum; and joining of copper and nonferrous metals to aluminum.
Armor Plate	Colalloy Armorplate	This armor plate weighs 50 per cent less than steel, and has a much greater surface hardness than ordinary armor plate. Its highly polished surface resists corrosion.	Designed for use in the construction of propellers, wings, fuselages, struts, gas tanks, and other parts for military airplanes.

Class of Material	Trade Name	Properties	Applications
Atomic-welding Material	Colaweld	A liquid, paste, and rod for the atomic welding of metals without the use of welding apparatus. Not intended as a substitute for welding by regular methods, but for work heretofore difficult or impossible to accomplish by ordinary welding methods.	The paste and rod are intended for practically all non-ferrous materials, including aluminum; the liquid and rod for stainless and low-carbon steels and practically all ferrous alloys. Metal from 0.005 to 0.050 inch in thickness can be welded.
Metal Coating	Colaweld Mermetal	A coating material that can be applied with a spray, brush, or as a powder and then heated by oven, torch, or other means to produce a fusion bond. High resistance to corrosion, abrasion, and erosion is provided.	Zinc, cadmium, tin, bismuth, lead, and their alloys can be applied to ferrous and non-ferrous metals by this process. Useful for high-speed production in the fields of marine construction, transportation, building and general maintenance.
Hard-surfacing Alloy	Colmonoy No. 4	A hard-surfacing alloy that has a hardness of 35 to 40 Rockwell C and can be machined without great difficulty. It is applicable to cast iron.	Suitable for application to forming and drawing dies and parts subjected to abrasion.
Hard-surfacing Alloy	Colmonoy No. 5	A hard-surfacing alloy that has a hardness of 45 to 50 Rockwell C and provides good wear resistance and freedom from galling, combined with moderate machinability.	Suitable for high-temperature steam valve trim and solid shaft bearing surfaces.
Hard-surfacing Alloy	Colmonoy No. 6	A hard-surfacing alloy that has a hardness of 55 to 60 Rockwell C, with high abrasion resistance and high compression strength.	Used extensively on parts having very small wear tolerances, and in cases where heavy pressures are encountered.
Galvanized Sheet	Colorbond	A galvanized sheet with a special surface finish which is more resistant to rust and provides a better bond for paints, lacquers, varnishes, etc., than the usual finish.	Available in three types of base metal: Steel, copper-steel, and pure iron-copper alloy, in a full range of sizes and gages.
Packing Material	Corroflex	A waterproof packing material consisting of a flexible, corrugated packing with criss-cross indentations, together with a duplex asphalt-lined sheet.	Useful in protecting metal parts and products against rain, hail, snow, or moisture.
Plating of Steel	Corronizing	An electrolytic process for applying alternate layers of nickel and tin to steel sheets.	Suitable wherever tin plating alone has been required. Effects considerable saving in tin.
Stainless-steel-clad Plate	Croloy	A carbon-molybdenum steel with thin sheets of chromium stainless-steel welded to it. Can be hot-formed, spun, or welded as easily as unbonded plate.	Useful where strength, as well as resistance to corrosion, is required.
High-temperature Alloy Steel	Croloy 7	Analysis:- Carbon, 0.15 per cent max.; manganese, 0.50 per cent max.; phosphorus 0.030 per cent max.; sulphur 0.030 per cent max.; silicon 0.50 to 1.00 per cent; chromium 6.50 to 7.50 per cent; and molybdenum 0.45 to 0.65 per cent. Offers considerable resistance to corrosion and oxidation.	Suitable for high-temperature applications, such as oil refinery cracking-still tubes and steam superheaters.
Copper-iron Alloy	Cuform	This material has an electrical conductivity about 70 per cent that of copper, and a tensile strength about equal to hot-rolled, low-carbon machinery steel. It has a tensile endurance limit 23 per cent higher than that of Cupaloy.	Particularly suitable for tips for spot welders, since it can be hardened by heat-treating and is softened very little by repeated applications of heat.
Phenolic Molding Compound	Durez 775	A general-purpose phenolic molding compound with excellent molding characteristics and a fast cure; will provide a smoother and more lustrous finish than the average general-purpose material.	As compared with other general-purpose compounds, it has lower water absorption, slightly higher flexural and tensile strength, and a heat resistance of 400 degrees F.

Class of Material	Trade Name	Properties	Applications
High-impact Plastic	Durez 1900 Black	A high-impact phenolic molded material, easily preformed and readily fed through hoppers and automatic feeding devices.	Suitable for production of molded parts that may be subjected to shock.
Molding Compound	Durez 1910	Third in a series of high-impact phenolic molding compounds. It preforms easily, and flows readily through standard feeders, as particle size is comparable to dry rice. Has a specific gravity of 1.45 and a bulk factor of 3.6 to 1.	Developed especially for such applications as bumper shoes, refrigerator lock-bolts, and other parts where minimum frictional resistance is desirable.
Phenolic Plastic Impregnant	Durez 7347A	A phenolic resin applicable to porous castings. Impregnation is accomplished under air pressure and is followed by baking with or without steam pressure. A smooth surface is formed that is practically impervious to water, solvents, mild alkalies, and acids.	For impregnation of porous castings that do not quite hold required pressure or where a smooth impervious surface is required.
Phenolic Molding Compound	Durez 8685	A material having high resistance to carbonization under an electric arc and that will hold its high dielectric strength when used at moderately high temperatures. It does not crack under expansion and contraction of metal inserts.	Developed especially to prevent "tracking" in cases where there is combined electric spark and rubbing action.
Blackening Process for Zinc	Ebonol Z	An immersion process for blackening zinc and its alloys. Immersion in a solution of the salts at 150 to 212 degrees F. results in a jet-black inorganic finish in from one to five minutes. Also can be used to produce black coatings on stainless steel, nickel silver, nickel, and the noble metals.	Can be utilized for blackening zinc-plated or hot-galvanized surfaces, as well as solid zinc and its alloys. Also applicable to nameplate finishing and blackening of etchings on rules, squares, tools, etc.
Metal-blackening Process	Electro-Ebonol	A process for the electrolytic blackening of almost all metals. Deposits are made in from 30 seconds to 3 minutes at 140 to 190 degrees F.	Aluminum, steel, stainless steel, zinc, cadmium, nickel, silver, gold, lead, tin, and various alloys can be blackened by this process.
Spring Wire	Electrometic	An oil-tempered spring wire of uniform physical properties and closely controlled fatigue values.	Suitable for a wide range of uses, such as brake springs, clutch springs, airplane construction, farm machinery springs, etc.
Tinning Flux	Fas-Tin-Flux	A concentrated liquid tinning flux of the zinc-chloride type. Has special addition agents to assure fast action, and is free from uncombined hydrochloric acid. Can be poured on molten tin without danger of explosion.	For use in hot-tinning, in the manufacture of terne plate (lead-tin alloy), and for soldering.
Protective Coating	Flexo Wax C and Diglycol Stearate S	An emulsion of these two products in combination with paraffin wax produces a water-repellent wax coating that protects metal.	For aluminum castings liable to attack by water condensation. Suitable on extruded parts and on zinc- and tin-plated products.
Packing Lubricant	Formula No. 610725	A compound that provides durable lubrication and makes an effective seal, with assurance against possible scoring. It forms an actual metallic surface, which quickly attains a polish or glaze when in contact with a moving member. Suitable for all pressures and for temperatures up to 1000 degrees F.	Intended for application to exterior surfaces of all types of packing prior to installation, and to stuffing-boxes after installation.
Powdered-metal Contacts	Giballoy	Eight grades of nickel-silver, silver-nickel-tungsten, silver-nickel-molybdenum and silver-nickel-cadmium powdered-metal compositions which can be produced in button, wire, strip, or rod form.	Can be headed into rivets or buttons for electrical contacts or coined to any shape required.

Class of Material	Trade Name	Properties	Applications
Sealing Compound	Glyceseal	A flexible, leakproof, and non-cracking compound that can be used on rubber as well as on metals. As it will not harden, joints once formed can be broken readily without damage to fittings.	Useful as a sealing compound for joints in pipes and containers carrying propane, pentane, butane, benzol, naphtha, gasoline, grease, and oils of all types.
Ferro Alloys	Crucival	These alloys are used to produce desirable properties in steel. One contains 26 per cent vanadium, 15 per cent titanium, and 10 per cent aluminum; another contains 13 per cent vanadium, 20 per cent titanium, and 13 per cent aluminum; while a third contains 30 per cent titanium, 20 per cent aluminum, and 6 per cent zirconium.	They make possible the production of steel of uniform properties from heat to heat; the conversion of some water-hardening steels into oil-hardening; the production of steel of unusual physical properties at economical cost; and the addition of alloys to steel without complicating the usual steel making processes.
Ornamental Metal Finish	Hammertone	Finishes resembling hammered silver, copper, bronze, and other ornamental metals are obtained by this liquid finish. A base coat of desired color is followed by a spatter coat of Hammertone liquid.	Can be applied to any kind of metal, and also to molded plastics. The finish is tough and durable.
Self-lubricating Alloy	Haneedur	A self-lubricating alloy with excellent wearing qualities. Its tensile strength is 90,000 pounds per square inch.	Designed to be used for valve stems and bonnets.
Welding Rod	Haynes 93	An alloying rod for hard-surfacing wearing parts. It has a tensile strength of about 42,000 pounds per square inch and a hardness (as deposited by oxy-acetylene welding) of 62 Rockwell C. When properly heat-treated, the hardness may be increased to 66 or 67 Rockwell C.	Successfully used on dredge pump impellers, cement-clinker crusher rolls, tamper feet for cinder block manufacturing, tube-bending mandrels, farm implements, and other parts where severe abrasion and moderate impact are encountered.
Steel	Hipersil	A silicon steel of high permeability. Its flux-carrying capacity is one-third greater than that of ordinary silicon steel.	Particularly applicable to transformer core construction. Its use permits reductions in size and weight up to 25 per cent.
Alloy Cast Iron	Hi-Tensilloy	A chromium-molybdenum cast iron suitable for forming and drawing dies. Is readily flame-hardened with air-cooling. When flame-hardened (without a water quench), it has a surface hardness of 450 to 600 Brinell, with case depths up to 3/32 inch. When wear occurs, dies can be renewed by flame-annealing, machining, respotting, and hardening.	Used for automobile-fender draw dies and automobile radiator-grille dies. Useful where volume of production is large.
Non-magnetic Steel	Jessop Non-Magnetic Steel	A free-machining alloy steel having a magnetic permeability of from 1.002 to 1.006 at 1000 oersteds magnetizing force at temperatures from sub-zero to boiling. Tensile strength, from 90,000 to 110,000 pounds per square inch; yield point, 55,000 to 60,000 pounds per square inch; elongation in 2 inches, 25 to 50 per cent.	Suitable for use in transformer, switch, and controller covers, entrance plates, spacing bars, end fingers, and numerous other parts of electrical equipment.
Protective Coating	Jetal	This is an improvement of a former process. Two-bath system produces a deeper black coating with simpler manipulation and control of solution.	Provides a black corrosion- and rust-resistant finish to steel.
Enamels for Plastics	Kem Iridescent Kem Plastic	An enamel applicable to plastic surfaces. Available in iridescent form (Kem Iridescent) or in solid colors (Kem Plastic). Applied by either dipping or spraying.	Useful in dressing up molded parts for vacuum cleaners, electrical wiring devices, radio cabinets, automobile parts, etc.

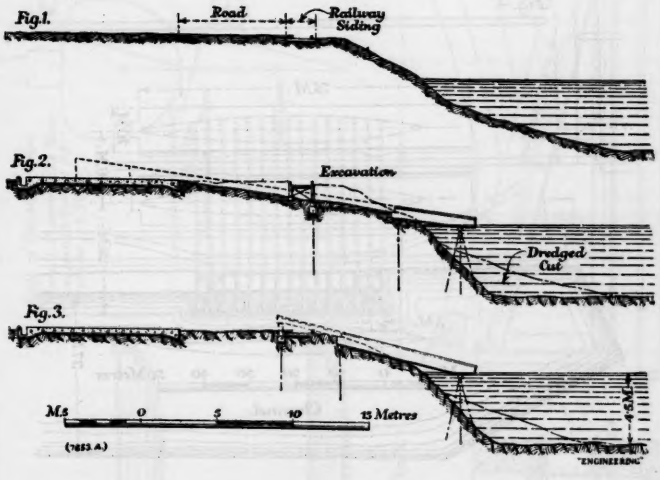
Class of Material	Trade Name	Properties	Applications
Machine Tool Finish	Kem Machine Tool Enamel	A faster drying synthetic enamel which provides greatly increased resistance to cutting compounds.	Intended specifically for machine tool castings.
Protective Coating	Koroplate	A grade of Koroseal paint for use under highly corrosive conditions. The base of this paint is a synthetic material developed from polyvinyl chloride. It can be brushed or sprayed at ordinary room temperatures. Available only in semi-glossy black.	Resists all acids except concentrated formic and acetic acids. Is not affected by brass-, chromium-, nickel-, cadmium-, zinc-, copper-, silver- or tin-plating solutions. Used for coating underground pipe lines and fume ducts in plating rooms.
Transparent Plastic Film	Koroseal	A synthetic thermoplastic material, processed into a transparent and highly durable film which is resistant to outside exposure, sun, oxygen, and extreme temperatures, as well as water. It is chemically inert and flame-resistant as well.	Used in laminated containers to hold acids and corrosives, and for insulating fine electric wire and cable. Also used in molded gaskets, grommets, and in acid and weather-resisting paints. Available in a variety of colors and also in translucent and opaque forms.
High-nickel Alloy	KR Monel	A high-strength, non-magnetic alloy having satisfactory machining characteristics combined with physical properties similar to K Monel. In hot-rolled form, it has a tensile strength of 90,000 to 120,000 pounds per square inch, with a hardness of 140 to 225 Brinell. In cold-drawn form, these values are higher.	Can be readily fabricated in automatic screw machines. Because of its non-magnetic property, it is particularly suitable in airplane construction. Has corrosion resistance similar to K Monel.
Synthetic Rubber	Liberty	A synthetic rubber produced from petroleum, natural gas, air and other natural materials. Does not swell or lose tensile strength when exposed to gasoline or mineral and vegetable oils.	Has proved preferable to natural rubber for gasoline hose and airplane expander tube brakes. Also satisfactory for automobile tires.
Steel Plate	Manganal	An austenitic, tough, non-magnetic steel containing 11 to 13 1/2 per cent manganese and 3 1/2 per cent nickel. Can be welded without subsequent quenching. Has a tensile strength of 140,000 to 150,000 pounds per square inch, an elongation in 2 inches of 72 1/2 per cent, and a reduction in area of 54 per cent.	Useful in electrical applications where non-magnetic characteristics are important. Also makes a good substitute for heavy castings where weight reduction is important, as in journal boxes, wear plates, mill liners, shovel buckets, crusher hammers, etc.
Metal Coating	Marlon	A plastic coating for metals that has a high degree of adhesion and is not appreciably affected by temperature changes. Can be applied by spraying, dipping, or brushing.	Used as a priming coat or alone, to protect metals against rust and corrosion. Particularly suitable as a coating for welds to prevent corrosion in seams and folds.
Photographic Material	Matte Transfer Film	A photographic material for sensitizing metal plates for the photographic printing of drawings by contact or projection.	Applicable in any field where metal templets are used in laying out operations.
Paste Solder	Multematic	A paste solder that can be brushed on any metal and heated by any means to its melting temperature, which is slightly above 400 degrees F. No preliminary cleaning or tinning operations are necessary.	Especially applicable where soldering irons are difficult to use, as in inaccessible spaces and on small parts.
Pattern Coating Compound	Metaline	Liquid metal compound designed to coat and seal wax fillets and gates preparatory to the use of "Patternseal." Reduces the usual hand-soldering by about 50 per cent when used as a bond between metal plates.	Can be applied as a heavy coating over small pin-holes in metal patterns or around edges for thin fillets; also as a bond between two surfaces, such as between metal hand patterns and metal or wooden plates.

Class of Material	Trade Name	Properties	Applications
Protective Metal Coating	Metacoat 404	A protective, invisible, transparent coating that can be applied by dipping, spraying, or brushing without special equipment.	Useful as a rust-preventive for steel, brass, and other metals.
Stripping Compound	Metastrip	A stripping compound, furnished in concentrated liquid form, which removes finished coatings by emulsifying action, leaving a bright clean metal surface. It contains no caustics.	Useful in stripping baked enamels, varnishes, lacquers, paints, japans, and new synthetic finishes from various metals.
Coating Material	Microchloe	A transparent coating material that dries rapidly to a high luster and has excellent adhesion, flexibility, and abrasion resistance. Can be applied by spraying, dipping, or brushing.	Provides excellent protection against the harmful action of sulphur dioxide, sunlight, moisture, oil, grease, gasoline, and chemical fumes.
Bearing Material	Monarch Metal	A bearing bronze manufactured in various high-lead combinations. Does not contain hard, abrasive tin and lead oxides. Superior hardness and compression resistance are provided. In cases of lubrication failure, seizing or galling of shafts is avoided.	Adapted to a wide range of bearing and seal applications. Less friction, heat, and noise are claimed to be produced by this material.
Aluminum Alloy	No. 40	This is a high-strength aluminum alloy, with a tensile strength of 36,000 to 40,000 pounds per square inch, a Brinell hardness (500 kg.) of 80 to 90, and a modulus of elasticity of 10,700,000.	For structural and decorative uses. Will take a high polish and has good resistance to corrosion.
Aluminum Alloy	No. 40-E	This is an aluminum alloy of high ductility. It has a tensile strength of 32,000 to 36,000 pounds per square inch, a Brinell hardness (500 kg.) of 70 to 80, and a modulus of elasticity of 9,800,000.	For structural and decorative uses. Will take a high polish and has good resistance to corrosion.
Light-weight Alloy	No. 301	This alloy is 66 per cent lighter than steel or iron; rustproof; non-magnetic; and has good forming, drawing, and electrical conductivity properties. Its ultimate tensile strength is 72,000 pounds per square inch; elongation in 2 inches, 32 per cent; yield point, 57,500 pounds per square inch; and hardness, 100 Brinell. Available in sheet, plate, rod, bar, wire, pipe, tubing, and extruded forms.	This is a readily fabricated structural material which lends itself to gas-welding, arc-welding, spot-welding, brazing, soldering, chemical-fusion welding, and reaction soldering.
Tool Steel	No. 773	A medium-carbon manganese-molybdenum steel possessing a high degree of toughness.	Suitable for dies, punches, cutting tools and chisels, stop-down dies, etc.
Pulley Covering	Nonslip	A sheet material that is wrapped around pulleys to prevent slip. Furnished in sheets of 9 square feet which are cut into strips of proper width.	A single application eliminates belt slippage for a period, usually, of two years.
Protective Coating	Parabar	A fast-drying, waterproof covering material made from chlorinated rubber. Unusually resistant to ordinary solvents, such as gasoline, kerosene, and lubricating oil, and also to alkalies, soda ash, and inorganic salts in dust or powder form.	Especially suitable for protecting steel work exposed to salt air. The metal primer also used has a lateral absorption action which turns up loose scale that might form subsequent defects in the covering.
Pattern Coating Compound	Patternseal	A coating that forms a protective seal against moisture penetration. It permits patterns to be used without a parting compound. One application usually lasts for a full day's run.	Developed for sealing and coating match plates, core-boxes, etc. Can be applied over shellacked, as well as new, wood surfaces.

Class of Material	Trade Name	Properties	Applications
Pickling Agent	Pickleen	A liquid wetting and penetrating agent which, when added to sulphuric or hydrochloric acid pickling solutions, reduces their surface tension and gives them greater wetting and penetrating action. It is added in the proportion of one pint to about fifty gallons of acid solution. It is non-inflammable, almost odorless, and harmless to the skin.	Used in pickling solutions for cleaning rust or scale; in acid dips before plating to insure clean work and to prevent peeling or blistering; for pickles employed previous to hot-galvanizing, hot-tinning, rust-proofing, painting, etc.
Plastic Shapes	Plastikmould Plastikrim	Extruded plastics shapes, manufactured in a wide range of colors and in the form of rods, tubes, and other commercial parts, both flexible and rigid.	Designed for use where aluminum products of similar shapes and sizes have been utilized.
Die Impression Compound	Plasul Bacelit	An impression checking material that is very light, does not shrink, and will show the finest markings of a form or die.	Particularly adapted for checking impressions of forging and die-casting dies. Can be used in place of wood patterns because of dimensional stability.
Metal Finish	Polymerin-160	A finish with excellent qualities of corrosion resistance and durability, combined with film hardness, luster, adhesion, toughness, and color retention.	For use where low-temperature, high-speed baking characteristics are important.
Waterproof Paint	Force-Tite	A white waterproof paint that can be used in any consistency from that of a cement-like compound for filling cracks and crevices, to that of a free flowing paint. The paint sets in about three hours, hardens in twenty-four hours, and requires about five days to cure thoroughly.	May be applied to cement, concrete, brick, stucco, clay tile, stone, asbestos sidings, and plaster board, but not to wood, plaster, metal, nor oily surfaces. Paint, calcimine or casein can be applied over it.
Bearing Bronze	Pre-Cast Bearing Bronze on Steel	A thin-wall, laminated type of bearing consisting of SAE 64 bronze bonded to steel. Has a higher Brinell hardness, lower coefficient of friction, and greater resistance to pounding and shock than ordinary cast bronze. Also available as a graphited bearing.	Available in plain or graphited form as finished bearings, washers, strips, or in rolls up to 400 feet in length.
Electrical Insulation Porcelain	Prestite	A porcelain for electrical insulation having a dielectric strength equal to that of wet-process porcelain, and a mechanical strength about 10 per cent greater under tension and cantilever loads. It is impervious to moisture.	Particularly adaptable for use in intricate shaped pieces; dimensions can be held accurate within 1 1/2 per cent.
Protective Metal Compound	Protect-O-Metal	Protective compound, resistant to heat, for use in welding and die-casting. Can be sprayed or brushed on metal. When sprayed on a die-casting die, it serves as a protective coating for at least twenty-five successive castings.	Used to prevent corrosion and the collection of spatter on metal surfaces during welding. Prevents castings from sticking to die molds. Also forms suitable priming coat for paint.
Metal Finish	Pyroflex	An inorganic finish having all the features of porcelain enamel, but requiring only one-half the burning time of baked-on enamels. Withstands heat and hard usage.	Available in a wide range of colors and grain finishes for use wherever porcelain enamel is called for.
Belt Coating	R-60-T	A synthetic coating which can be brushed on belts of all types. Samples of belting, when so coated and placed under severe tension, have shown no evidence of deterioration after six months' exposure to all kinds of weather.	Particularly useful for protection of outdoor conveyor belting from deterioration through action of sunlight and air, especially during idle periods.
Flexible Tubing	Resistoflex	Tubing made in sizes up to and including 1/2 inch inside diameter, from a flexible synthetic resin, insoluble in gasoline, oil, ether, and alcohol. Has extreme lightness (weight about one-half that of aluminum), great toughness and strength, good elasticity, and a high degree of flexibility.	Used chiefly in fuel and brake lines; in lubrication systems for automotive equipment, aircraft, and Diesel engines; in chemical and process industries for conveying solvents and oils; and in hydraulic lines.

Class of Material	Trade Name	Properties	Applications
Synthetic Substitute for Zinc Coating	Rezagrome	A corrosion-resistant synthetic coating that has shown a high degree of protection against caustic and acid solutions, in comparison with zinc coatings.	Used as a substitute for galvanized coatings on air-conditioning equipment, motor trucks, fans, blowers, pumps, and special machinery.
Vinylidene-chloride Plastics	Saran	Group of plastics ranging from a flexible, moderately soluble material with a softening point of 70 degrees C. to a hard, tough thermoplastic solid with a softening point of at least 150 degrees C. Tensile strengths range up to 60,000 pounds per square inch. These materials have a high degree of flexibility and resistance to fatigue. They are odorless, tasteless, non-toxic, and are characterized by extreme chemical resistance.	Available in the form of strong, flexible, rattan-like strands, extruded tubing, and other shapes. Used as a resinous bonding agent for new type of abrasive wheel. Can be molded by compression or injection. Almost any shade of color and degree of opacity can be obtained.
Stainless-steel Clad Sheets	Silver-Ply	Mild steel sheets and plates of flange quality, bonded with stainless steel of 3 to 50 per cent of the total thickness. These sheets can be bent, spun into deep heads, deep-drawn, drilled, and otherwise worked with greater ease than solid stainless steel.	Useful for manufacture of cooking vessels, storage tanks, marine equipment, and other applications where corrosion and erosion are problems.
Powdered Metal	Sinteroy	A powdered metal than can be pressed into practically any shape and sintered to produce a dense, homogeneous steel. The forming pressure is 50 tons per square inch, and sintering is usually accomplished at 1945 to 2100 degrees F.	Suitable for production of such parts as gears, cams, pump rotors, washers, pins, rivets, and splined shafts. Said to compare well with cast steel and cast alloy steel.
Open-hearth Steel	Speed Case	A specially processed, low-carbon, open-hearth, case-carburizing steel having the machinability of S A E 1112 and X1112 Bessemer screw stock, and the strength of S A E 1020, X1020, X1314, and X1315 open-hearth steels. Relatively high sulphur content makes dry machining possible. Can be cut at surface speeds of 220 to 260 feet per minute with greatly increased tool life.	Suitable for all types of broaching operations and cold heading, rolling, or crimping. Makes sound forgings and after forging, machines rapidly. Is readily welded by either electric-arc or gas process. Also useful for non-magnetic applications.
Metal Adhesive	Strengl-Hold	A two-element adhesive consisting of a powder and a liquid which are mixed shortly before using. A metal-to-metal joint, 2 by 2 inches, will support approximately 1250 pounds. A glass-to-metal joint of the same size will support up to 1450 pounds. The adhesive is unaffected by many corrosives, but is attacked by rubber solvents and by copper and manganese in solution.	Suitable for joining metal to metal, glass, wood, or other materials, glass to glass, and wood to wood or glass. Also makes an excellent coating for protecting metals of all kinds against atmospheric and other forms of corrosion.
Plastic Valve Packing	Super-Seal	Improved packing that utilizes non-frictional, vulcanized tape in place of frictional woven-cotton jacket. The packing contains a dry-graphitized plastic material made from long-fiber asbestos, anti-frictional metal particles, and special binders.	Suitable for centrifugal and rotary service, as in feed-pumps, low-pressure steam rods, expansion joints, etc.
Aluminum Alloy	T-1	A copper-tin-magnesium-zinc alloy of aluminum developed for heat-treated sand castings. Without heat-treatment, it has a tensile strength of 30,000 to 33,000 pounds per square inch; an elongation in 2 inches of 6 to 10 per cent; and a Brinell hardness of 60 to 75. Also has good resistance to salt water corrosion.	Can be used without heat-treating and quenching, and can be welded without deterioration in physical properties. Meets all requirements of U. S. Air Corps Spec. 11234 and 11235, and U. S. Navy Aeronautical Spec. M-397.
Floor Covering and Filler	Trad Seal	A liquid covering that can be applied to floors with a steel trowel for surface protection, and is ready for heavy service six hours after application.	Serves as a waterproofing, crack-filling, and splinter-proof covering for wood or concrete floors.

Class of Material	Trade Name	Properties	Applications
Copper Alloy	Trodaloy	A copper alloy containing beryllium and chromium that is much harder and tougher than copper. Particularly useful in withstanding the high pressures and impacts encountered in welding.	Useful for welding electrodes, switch plates, cams, spring fingers, and mechanical parts requiring high electrical conductivity.
Alkaline Copper-plating Process	Unichrome	An alkaline copper-plating process that provides a smooth, fine-grained base for bright nickel-plating. The plating bath is non-corrosive to flesh, clothing, and equipment, and forms no salt crust on tank, work-rods, or anodes.	Use of this process makes possible a reduction in the amount of nickel used for plating.
Magnetic Alloy	Vicalloy	An alloy composed of cobalt, vanadium, and iron that can be made to hold more permanent magnetism than any commercial material previously developed. It can be drawn and rolled without losing its magnetism.	This alloy has been applied in the form of a tape for sound recording purposes.
Welding Rods and Fluxes	Weldoloy	Rods and fluxes for oxy-acetylene welding and brazing at low temperatures. Various types are available for different classes of work. *Type CI-514*, which is the color of cast iron, is a medium hard material with good machining qualities. It has a fusing temperature of 1500 degrees F. and a tensile strength in the weld of 47,000 pounds per square inch. *Type ST-516*, of a silver-white color, has a fusing temperature of 1350 degrees F., a weld tensile strength of 110,000 pounds per square inch. *Type BU-685*, which is of bronze color, has a fusing temperature of 900 degrees F., a tensile strength of 100,000 pounds per square inch, and a Brinell hardness of 235. It is non-corrodible, has a low coefficient of friction and can be highly polished.	*Type CI-514* is used for welding cast iron, filling up blowholes, and building up new material on worn-out castings. *Type ST-516* is used for butt-welding steel, stainless steel, chromium-nickel steel, molybdenum and vanadium steels, Carboloy and tungsten-carbide alloys, mild steel, and malleable cast iron. It is particularly suitable for welding thin steel sheets and tubing. *Type BU-685* is used for building up materials on worn-out parts of steel, cast iron, copper, brass, bronze, and nickel alloys. Useful for repairing guide faces, valve-seats, ship propellers, etc. *Type BB-518* is used for welding brass, bronze, copper, aluminum-bronze and nickel, and for welding copper alloys to iron, galvanized iron, and steel; *Type WM-688* for white-metal die-castings; *Type SA-690* for sheets and tubes of aluminum and its alloys; and *Type CA-710* for welding aluminum castings and for building up new material on worn parts.
Tool and Die Steel	Windsor Special	A chromium-molybdenum-vanadium type of steel which is air-hardening, easily machined, extremely tough, and has a wide hardening range.	Useful for tools or dies where the initial cost must be kept at a minimum. Can be hardened or tempered in either oil or air.
Plastic and Metal Adhesives	XL-5041 XL 5075	Adhesive solutions made of Vinylite resins, which produce strong, impact-resistant, metal-to-metal or phenolic-to-phenolic bonds. Joining of parts is under heat and pressure.	Tension tests indicate a shear strength of 4000 pounds per square inch; impact strength is better than that obtained with regular grades of polyvinyl acetate.



On the timber launching ways, 15 in number and 300 millimeters wide, the pressure on the lubricant is much the same as on the yard's longitudinal slipways, that is about 2 kilograms per square centimeter. The building berths themselves were reinforced-concrete rectangular platforms 10 meters by 75 meters. No piling was necessary under the berths, a section of which is shown in Figure 8, on page 86. One great advantage is that a vessel on such a berth can be built with the keel horizontal. On most lengthwise berths a ship is built with a certain inclination, so that all bulkheads, frames, etc., must be erected with the aid of a plumb line or spirit level.

A section of the site with two submarines under construction is given in Figure 9, and in Figure 10 is shown diagrammatically the launching procedure for the submarines built farthest from the canal. After wedging up the vessel and removing the keel blocks, the launching procedure begins with the horizontal "fleeting" through a distance of 26 meters from position I to position II, Figure 10. The vessel slides on the 15 rails of 300 millimeters by 300 millimeters timber baulks, which are coated on the sliding surfaces, first with English launching tallow and then with soap.

Two hydraulic jacks start the movement, after which two six-sheaved tackles are used, each coupled to its own drum, which is driven by a compressed-air motor. A plan of this arrangement is given in Figure 11. About 2 hours are required to shift the vessel along the 26-meter stretch. As soon as the vessel comes to position II, Figure 10, the inclined launching plane, with a slope of 1 in 4, comes into use. The upper and lower parts of the launching cradle (Figure 12) are connected to a winch during the horizontal motion, and this winch must be released before the vessel can begin to move down the slope. Moreover, the lower part of the cradle must be secured so that it cannot slip back.

Precautions are specially necessary against the risk that the vessel will run away down the 12-meter length from position II to the water, and severe damage can be caused if it should begin to slip in either direction

Fig. 4.

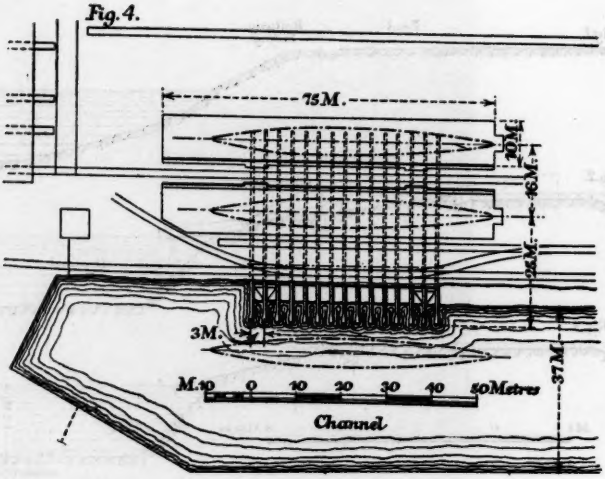


Fig. 5.

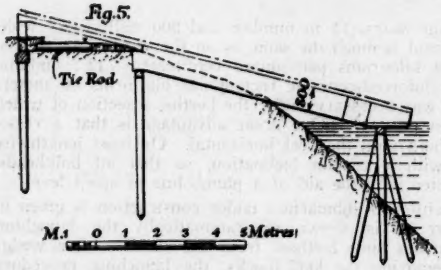


Fig. 6.

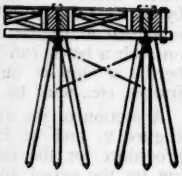


Fig. 7.

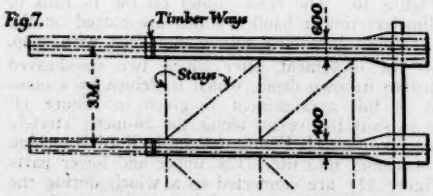


Fig. 8.

Fig.9.

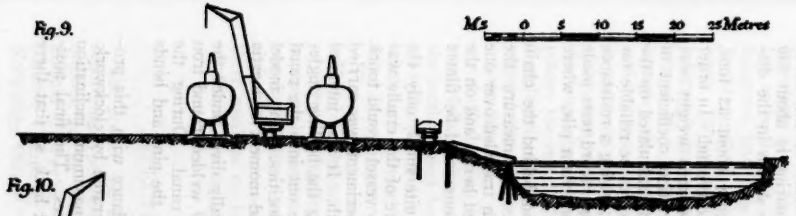


Fig.10.

Fig.11.

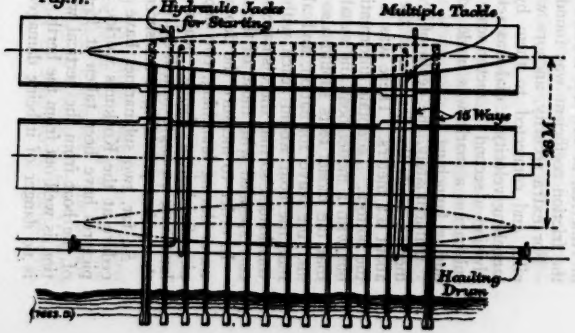
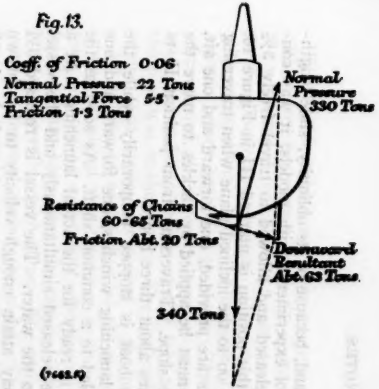
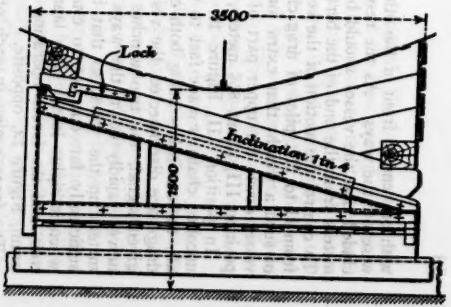


Fig.12.

Fig.13.





with one end in front of the other and, because of its obliquity, slide lengthwise off the ways. As the result of experiments with models, it was concluded that the vessel should be released and allowed to travel freely 3½ meters from the end of the berth; this position is marked III in Figure 10. To control the motion of the vessel on to the inclined plane when traversing from II to III, piles of drag chains are provided, one forward and one aft, of such a weight that extra force must be applied by tackles to move the vessel down the upper part of the slope. Traversing from position II to position III, about 8½ meters, takes about three hours.

In position III, Figure 10, the boat is stopped temporarily while the uncoiled chain is made fast to the launching winches, one forward and one aft, these winches being both coupled to a common shaft. As soon as the drags are disconnected, the vessel is ready for the actual launching. At a given signal, the two winches are released simultaneously and the vessel moves rapidly down the ways into the water. The vessel is released 3½ meters up the ways, so that it may attain enough velocity to be thrown sufficiently far out not to crash against the concrete ends of the berth when it rights itself. The launching weight of the submarine is about 340 tons, and the forces operating during the launching are shown in the diagram, Figure 13, opposite.

The force acting in each of the drag chains, averaging about 32 tons, must overcome the friction of the drag weights against the ground. In order to determine the friction coefficient, a chain pile of 30 tons weight was dragged along the ground. This experiment gave a friction coefficient of 0.78 at starting and of 0.73 when in motion. The weights calculated on the basis of these values, as applied to the first launch, proved to be reliable for heavier masses, as the chains cut down into the loose soil, giving a resistance coefficient of at least 0.90. Reports in Marine Engineering record tests made in America, at Messrs. Ingall's shipyard, with a 120-ton chain pile, where the friction coefficient was found to be 0.90.

For extra security, anchors were buried in the ground behind the chain piles and connected to them by means of gin blocks. To measure the launching velocity, a dial was set up with a pointer which travelled over one division a second; a meter scale was painted on the fixed berth, and on the submarine a mark was made so that the relative motions could be filmed during launching.

Unfortunately, the depth of water in the canal was quite small, only 4½ meters, while the draught of the vessel to the lower edge of the cradle was about 3.2 meters. There was a risk, therefore, that the vessel would touch the bottom. To obtain information on this point, an experiment was carried out with a model boat and canal to a scale of one-fiftieth. It was intended that the model tests should also provide data concerning the heeling angles and the wave formation, and also indicate the distance out into the canal that the boat would reach with different launching velocities. The model was loaded so that the displacement, center of gravity and moment of inertia corresponded with those of the actual submarine.

In order to measure the depth to which the boat actually dives under the water during launching, two depth meters were made of welded round iron pins fixed in a channel beam placed on edge in the canal. During the launching an angle iron fixed to the cradle sweeps over the pins and bends them, thus providing a measurement of the actual drop.

So far, two submarines have been launched in accordance with this procedure at the Kockums works, and, with a camera operated by clockwork, pictures have been taken at ½-second intervals. The maximum inclination of the boat from the vertical was found to be 36 degrees. The final position is well out from the berth. The boat does not float back, so that there is no danger of it being damaged against the berth.

The first launching was very interesting to watch. The final velocity was 3.25 meters per second when the center line of the boat passed the end of the ways and it took about 2.5 seconds from the release of the trigger until the boat entered the water. The second launching was not in accordance with expectations. From the moment of release, the boat remained for two seconds before beginning to move. Then the after end started. After another second, the forepart began to move and half a second later the boat was seen to be travelling equally fore and aft. Five seconds after release the boat was in the water. The final velocity was 2.9 meters per second, as against 3.25 meters per second in the previous launch.

In seeking an explanation of the reason for the delay after the release, it was calculated that the force in the direction of the slope was about 63 tons, and as no mechanical obstruction could be found, it was clear that friction must have been the cause. This involved a friction coefficient of 0.19, an incredibly high value. The temperature was 10 degrees C. and had varied 5 degrees during the night. The reason appeared to be that the boat had been stationary for about three hours, waiting for the arranged launching time. The two tallow-coated surfaces had adhered and the tallow had to be sheared in launching. Experiments carried out later with a 1000-kilogram test weight showed the same result. When the lubricant was freshly applied, an inclination of 1 in 5 was sufficient for the test weight to move. When the lubricant had been for 23 hours under the same load (2 kilograms per square centimeter) as in the launching process, a slope in excess of 1 in 3 was required to start the weight. As, in the actual launches, the berths had an inclination of only 1 in 4, it was evidently an accident that the boat commenced to move at all. In arranging launches, it is necessary to ensure that the boat does not remain at rest for any appreciable time in the final position, but is released immediately after it reaches the launching position. On examination in dock it was found that, in four places, the vessel's hull had small indentations in the strakes, 6 millimeters or 7 millimeters deep, but as the plating was thin (3 millimeters to 6 millimeters) the damage was easily repaired.

Side launching, properly carried out, is a method which does not strain the ship's hull, as it avoids the prolonged stressing which occurs when the stern lifts during an endwise launching. In America, the author has seen the method used for 12,000-ton ore-carrying ships with a launching weight of 5500 tons and a length of 180 meters. There is certainly some shock when such a vessel strikes the water, but it is no greater than those encountered at sea in heavy weather.

The side-launching installation at the Kockums yard, consisting of two building berths and one launching berth, cost only about one-third of what a corresponding longitudinal arrangement would have done, and the time occupied in construction amounted to about a quarter of that estimated for one longitudinal berth. The arrangements made have proved satisfactory and, with the experience gained in launching these relatively small vessels, there need be no hesitation in using side-launching for large ships if the conditions are suitable in other respects.

SELECTION OF SUBORDINATE PERSONNEL.

The proper use of tests, interviews, and application blanks in selecting subordinate personnel are described in this paper presented at the June meeting of the American Society of Mechanical Engineers. The author, Harold C. Taylor, is employed at the Hawthorne Works of the Western Electric Company. His paper was published in Mechanical Engineering, November, 1941.

We are going through a period now when the demand for improved selection methods, along with improved training methods, is doubtless greater than it has been for nearly twenty-five years. Every business and industrial organization needs to hire men who can learn their jobs quickly; who can reach high standards of efficiency on repetitive jobs; who can remain stable under pressures; and above all, men who have whatever it takes to develop rapidly for higher-grade and supervisory positions.

With the selection problem thus looming up with increased importance, it is natural that increased attention should be paid to those procedures which the books on personnel administration have called "scientific selection." It is to these principles of scientific selection that I wish to call attention today. It seems that our attention might most profitably be devoted to these principles for two reasons: First, those employers who have now turned their attention to the possibility of scientific selection are sometimes under the impression that there is some single mysterious formula, some "open sesame," which can be applied more or less without change to any specific employment problem in such a way as to yield immediate and adequate results. Unfortunately, there is no such formula. There are only some techniques and points of view which are helpful in working out improved procedures in a specific situation.

Secondly, it is widely felt that this formula for scientific selection, whatever it is, is unerringly accurate in its power to choose exactly the right man for each and every job—to fit without error square pegs into square holes and round pegs into round holes. It is often believed that the technician in the field of so-called "scientific selection" will be able to accomplish something equivalent to drawing rabbits out of a hat.

Unfortunately, this hope also is much too optimistic. The procedures of scientific selection do make possible a definite improvement in selection of personnel. There is abundant evidence that this is so. But those who hope for miraculous results are due to be disappointed.

You who are here today are largely the men who in your own organizations will determine whether new selective procedures should be installed in your employment offices, and you are the ones who will be called upon to pass judgment upon the worthwhileness of such procedures after they have been tried out. It seems, therefore, that a discussion of the principles of and points of view toward these techniques will serve your needs more adequately than any detailed elaboration of procedures.

Three Techniques.

There are three fairly distinct techniques which require some discussion, these are: (1) The weighted application blank, (2) the planned interview, and (3) employment tests. While we shall devote most of this discussion to an evaluation of tests, these three techniques will be discussed in order.

1—The Weighted Application Blank.

Let us turn then to the "personal-history analysis" or "weighted application blank." The usual application blank covers a good many items of information which can easily be obtained from applicants on paper and in a very short length of time. These are, for example, age, education, marital status, number of dependents, racial background, and perhaps such items as amount of life insurance carried, possession of an automobile, and so on. Many times it would be difficult to give a very clear reason as to why some of these things might bear on the success of applicants in the occupation under consideration. Nevertheless, such items of information are so easily and cheaply obtained that it is often worth while to check them against a

group of outstanding employees in the occupation and a group of relatively less successful employees in order to determine whether such items do in fact distinguish between the two groups.

Sometimes this type of analysis is strikingly successful. For example, the Life Insurance Sales Research Bureau has used such techniques in developing a weighted application blank for life-insurance salesmen. They have found that a high group of agents could be chosen with this technique such that their first-year sales volume would be nearly twice as high as average first-year production, and four times the production turned in by the lowest group.

Before adapting such techniques to your own uses in selecting industrial personnel, we would suggest that you look at each tentative item in order to determine whether the people whom you would normally choose for the particular occupation vary to any great extent with respect to that item. For example, your obvious job requirements and your labor supply may be such that the age range, the educational level, and the racial stock of potential employees may be quite uniform. In that case, there is not much point in studying intensively the minor variations of applicants in these respects.

2—The Planned Interview.

The planned interview is based upon one fundamental principle: That the best indication of what a man will do is what he has done; or that the kind of person a man has been is very much the kind of person he will continue to be. In everyday life among our friends and business associates, this is the basis upon which we guide our actions toward them. A wife learns to detect the precise moment at which her husband will be reminded of his favorite story. Men learn with considerable precision at what hour of the day the boss can best be approached, what words to use in obtaining his approval, and so on. This type of prediction does not necessarily involve knowledge of psychological theories on the part of any of us. It involves only a recognition of the fact that, generally speaking, people do not change. Throughout a considerable variety of environmental situations they will continue to act according to their habits.

To some extent, employment interviewers have always made use of this principle. We regard it as significant if we discover that a man has held one job for as long as three years, simply because that fact offers at least a shred of evidence of his job stability. If he has held twenty jobs in the last three years, we regard that as some indication that he will continue, for whatever unknown reasons, to flit from one job to another. The planned interview is simply a term to describe a more conscious, more systematic, and more enlightened direction of the interview toward the objective of discovering and interpreting the significant aspects of what a man has thought, what he has been like, and what he has done. Too many interviews include aimless discussions of the weather, the foreign situation, or yesterday's ball game. The things we should be looking for are those recurrent forms of behavior which the applicant has shown, time after time, which we may take as evidences of what he will be likely to do tomorrow and next year.

The most obvious problem which will occur to you, we suppose, is that the conduct of such an interview does take time and that there is a problem as to whether the devotion of so much time to the selection of unskilled factory personnel, for example, could be justified. In this connection, one cannot help feeling that since a man on the pay roll usually represents a rather sizable investment on the part of the company, the devotion of another hour or two of time before he is placed on the pay roll might easily be defended. However, what should be emphasized most just now is the

importance of conducting the present interview along planned and organized channels rather than haphazardly. It is entirely possible that more improvement in selection could be made through some effort along this line than is likely to be made by the use of any other employment techniques. The employment interviewer's judgment carries very heavy weight in the final choice of personnel, and no doubt should continue to carry heavy weight. Anything which can be done to sharpen that judgment should be very much worth while.

This topic deserves a session in itself, but we think that the principles of the planned interview are so obvious, once they are pointed out, that they will be readily acceptable to all of you. We should, therefore, like to turn to another selection technique which is subject, perhaps, to more misunderstanding. This is the employment or "psychological" test.

3—The Employment Test.

All would agree that the best test of performance is the test of life itself. The only sure way of determining whether an individual will succeed to any specified degree in performing a job is to place him on that job and see how he turns out. No one should pretend that there is any other infallible method of determining whether or not people can succeed in any given vocation.

But this, of course, is a very costly and time-consuming procedure. From the standpoint of the individual, there is a limit to the number of vocations he could possibly try out in such a manner. From the standpoint of an organization which desires to have its work done as effectively as possible, the procedure of tryout on the job is expensive, both from the standpoint of training, and from the standpoint of the effectiveness with which the job gets done.

A "test" is simply a quick way of finding out, as well as we can, what the results of a job tryout would have been. In this respect, a test can be thought of as analogous to the "test sets" used in the inspection of raw materials and industrial products. A complicated machine (the applicant) is delivered to the door of the employment office for potential use in the performance of some function. Various sorts of meters (tests) are applied to this complicated machine in order to make an estimate of the probable effectiveness of that machine in performing the function to which it is to be assigned. It may be useful, because of your familiarity with inspection tests in engineering work, to carry this analogy with employment tests a bit further.

It is the job of the test technician to devise these "inspection-test sets" in such a way that the results of the inspection will yield a larger proportion of effective product than would be the case if those test sets were not used.

Reliability and Validity of Tests—The test technician sets up two main requirements for his test sets: That they must be reliable and that they must be valid. These requirements are not mysterious at all. They are the same as the requirements which would be demanded of any meter or measuring device in the engineering field. Reliability means simply that if you apply the test set twice to the same machine, the reading must be substantially the same. We are all familiar with the fact that some measuring devices, particularly rough methods of arriving at quick approximations, will give results that vary slightly from time to time. In other words, the "reliability" of such meters in any field is not perfect. In other fields we may often get around this difficulty by taking several readings. This is exactly the procedure often used in giving psychological tests. If one read-

ing is not accurate enough, we take additional readings. This means giving the same test again, or giving other tests of comparable type.

The second requirement of a test in any field is that it must be valid. This means simply that readings on this meter must be related to the effectiveness of the material which is being tested. This concept, also, is common in the engineering field. For example, thorough and precise methods may be worked out for the testing of some characteristic of a material or product in the scientific laboratory. This thorough and highly precise test is likely to be costly and time-consuming. The engineering problem, then, can be stated as one of developing some quick and inexpensive way of arriving at somewhere near the same result. In soap cooking, for example, there are precise methods of determining in the laboratory whether or not a kettle of soap has cooked long enough. However, if one waited for the results of such an analysis, the kettle of soap would already have cooked too long. Consequently, the soap cooker has to learn to tell by feeling and tasting the soap when it has cooked long enough. In this case, the extent to which the soap cooker can make the same decision every time under comparable circumstances is his reliability. The extent to which his decisions are right is his validity.

In the case of the employment testing of candidates for positions, the chemical-laboratory test which we wish to approximate is the test of life itself in that vocation. The problem is to develop some shorter way of approximating as well as we can the results of that test.

There are, thus, many points of similarity between the construction of a device for inspecting human material and the construction of a device for inspecting any other type of material. The technical skill of the technician who is engaged in this work does not consist in any mysterious mind-reading capacity which some persons think he has and which others insist he does not have. He is engaged in the making of devices which are much more comparable in principle to an electric meter or a chronometer than they are to a crystal ball or a divining rod.

How Valid Are Tests?—There is one important distinction which needs to be made between the meters with which most of you as engineers are familiar and these meters or tests which are used in the prediction of the future performance of human beings. The meters that most of you use in your engineering work are highly valid—that is, they predict with considerable accuracy the future performance of the devices you are testing. On the other hand, the meters which we use in gauging the potential future performance of human beings do not predict that performance with anything like the accuracy to which you are accustomed. Generally speaking, it will happen with any test or any series of tests used in predicting human performance that a few persons who do poorly on the tests will turn out well on the job if given a chance. Even more often, it may happen that some who do well on the tests will be found not to succeed in the test of life itself.

There is no doubt that this difference between the predictive power of mechanical, chemical, or electrical tests, and the predictive power of psychological tests has led some engineers to become doubtful of the value of psychological tests. They are accustomed to working with tests of such high precision that the relatively low predictive power of psychological tests leaves them disappointed with the usefulness of such devices.

Three Reasons for Relatively Low Validity of Employment Tests—There are three very good reasons, I believe, for this sharp difference in predictive power. The first of these is that a good many of the factors which determine what is going to happen to an individual in months and years to come are not inside his skin at all. They are environmental factors which

may vary from those he has previously met in ways which we cannot at all foresee. His wife may die, his children may cause him trouble, he may work for a boss who affects him adversely, or his health may change markedly. All of these unpredictable factors will affect his future, as well as those factors inside his skin, to which we are confined when we attempt to test him in any manner and predict his future.

The second reason why the predictive power of psychological tests is less than that of mechanical or electrical tests is that in testing mechanical or electrical devices, we are ordinarily concerned very directly with the extent to which the device performs at the moment in the manner in which it was intended to perform. We do not have to make any very far-reaching inferences from its ability to perform in a certain manner to anything about the future ability of the device to perform in some other way. The testing of mechanical or electrical devices thus approaches what we call "proficiency testing" or "trade testing" in the inspection of human materials. For example, if a girl says she can type at a certain speed, we can test her possession of that skill with a high degree of accuracy. If she says she can take dictation accurately at certain speeds, her skill can also be tested with considerably accuracy.

By contrast, however, it will be noted that in most psychological testing, the person being tested cannot perform at all the functions for which we wish to test him. We are always in the position of inferring from the present behavior of the individual on certain tasks what his future performance will be on other tasks which he cannot now do. Sometimes these other tasks in which we wish him to achieve proficiency differ markedly from anything he can do now. Under those circumstances, of course, it is not easy to determine with assurance what aspects of his present performance may serve as reasonable clues to his future behavior. This longer-range forecasting of potential future performance on untried tasks is called "aptitude testing," and constitutes most of what you think of as employment testing.

There is a third reason why tests of human future performance are not as valid as most tests of mechanical devices. This is that the factors within a man's skin which make for his success in any activity as complicated as success on a job are large in number and complex in their interrelationships. We cannot hope to cover in our testing of the raw material which stands before us as a potential candidate all or even a high proportion of the factors within him which will influence the degree of his success or failure. Out of the multitude of such factors which in reality bear upon his future, we can test only those which we have been able to identify as being of substantial importance; and even among those, we can test only the ones we have learned how to test with some degree of accuracy.

Tests Do Improve Our "Batting Average"—Thus it is that the engineer is bound to be disappointed with the results of psychological tests if he expects to find the precision to which he is accustomed in his own work. It seems to us, however, that when he is faced with the results of psychological tests, he should not infer therefrom that the tests are no good. He is faced, in reality, simply with new evidence of what he has known all the time, namely, that the human being is a highly complicated machine as it stands, made up as it is out of the interrelationships of countless hereditary factors and innumerable experiences. Thus the prediction of the individual's success in some untried field as he meets further unpredictable environmental factors is a difficult job.

Nevertheless, the making of those predictions, however difficult they may be, is a job which we cannot escape. Employment men are making such predictions every day, and so are line supervisors who accept or reject

candidates submitted by the employment office. Tests must be evaluated simply upon the basis of whether they improve our present practice in making these inevitable decisions—not on the basis that they fall short of perfection.

There is an abundance of evidence that, looked at in this modest way, tests do improve our batting average in selecting the right man for the job. From the technical and professional journals in this field, we doubt that it would be any trick at all to accumulate a five-foot shelf of literature containing nothing but evidence of the substantial, though not miraculous, contribution which tests have made in various business and industrial situations in the selection of personnel. Although it might be dramatic for us to quote some of this evidence, and might lend conviction to our statements, we feel, as indicated at the outset, that a statement of principles and points of view toward tests is all we can hope to cover at this time. It has been our experience that most of the confusion which exists concerning the usefulness of tests is due to the fact that these basic considerations have not been kept sufficiently in mind.

Those of you who wish to investigate further the evidence concerning the usefulness of tests, and who wish to know more about specific tests which may be of use in your own organizations, will be interested in looking over a recent report by Dr. Herbert Moore, entitled "Experience With Employment Tests," and published by the National Industrial Conference Board last March. For the moment, we should like simply to offer a few comments concerning the pitfalls into which those who first undertake the use of tests sometimes fall.

Some Cautions in the Use of Tests—1. Don't expect too much from tests. Keep in mind that tests will not bring about perfection in the complicated job of selecting people. They will serve only to improve the batting average.

2. Don't allow the use of tests to relax your present employment procedures, which give heavy consideration to the judgment of the experienced employment interviewer. The employment man should not be made to reject a candidate who looks good to him, simply because that candidate made a low score on the tests. The converse of this is even more true; don't accept for employment a man who doesn't look good to you, just because he made a high score on some test. Ideally, a man should be hired only when all of the criteria for selection are favorable.

3. If you decide to go into the testing of employees, don't devote too much time to the invention of fancy-looking gadgets. The invention of a shiny new manipulative, assembly, or coordination test has been a favorite pastime of newcomers in the testing field for a long time. The development of such apparatus tests is laborious and expensive, even when done by an expert. Usually they are expensive to give and to score. When not developed by an expert, they are often also weak in the two essentials of any measuring device—reliability and validity. It is much better to make a fairly good choice from among those tests which have already been developed and used under circumstances which appear to be comparable to your own.

4. Don't get involved in the use of a large number of tests in your employment office. If you pick tests for each occupation with which you are concerned, strictly on the basis of the ideal setup for that occupation and without regard for your over-all employment picture, you may wind up with such a large number of tests which have to be given to the applicant that the program bogs down and takes an inordinate amount of time. Fortunately, it is usually possible to get along with a relatively small number of broad-purpose tests without a great deal of loss of effectiveness in predicting for any one occupation. If one chooses two or three fairly good

tests for one occupation, it usually happens that the addition of other tests, no matter how relevant they may appear to be, will not make much added contribution to your predictive power. Successive tests after the fourth or fifth, at least, usually yield very small additional returns.

5. Don't give much thought to the use of tests in occupations where your hiring volume is very small. Tests offer their greatest potentialities under conditions of fairly heavy volume.

6. Don't try to install a test program without technical assistance from someone who has had experience in that field. I don't mean that there is anything esoteric about making tests work. But there is, after all, a considerable body of technical literature in the field on which one should capitalize in lining up his own program. There are special statistical techniques which are not exactly the same as those commonly used in solving business or engineering problems. And there are matters of interpretation of test results, on which one may easily go astray.

Can Tests Be Put to Use on Short Notice?—With regard to this whole problem of the usefulness of tests to you in your present hiring emergency, we know that many of you are thinking that the installation of tests in your employment office represents a slow and expensive proposition. Your present problem, it is recognized, is not one of making long-range plans for the future, but of doing as well as possible the hiring job which must be done right now. Is it possible to short-circuit in any way the rigorous process of tryout and calibration of tests, so as to make them more or less immediately available to you for your present needs?

We are personally convinced that it is possible for the test technician to offer you such immediate help in the selection of personnel for most of your larger-volume occupations. We must emphasize, by way of qualifying this point, that there are relatively few test technicians in the country today who will offer you such immediate help; and we are afraid that some of those who are most eager to do so may tend to be among the less experienced men in the field.

There are a number of good reasons why competent professional men in this field tend to be unwilling to do what they can for you without thorough scientific experimentation. We have not the time to go into those reasons in detail, but there is one which seems to us to be worth calling your attention to.

Let us bear in mind that when the test technician has finished his job of "calibration," he has obtained proof that the results of his tests do actually check with the ultimate test of life—that is, with success in the vocation for which he is predicting. That proof is essential from a standpoint which is very important to a technician in any profit enterprise: A demonstration that one's efforts have been worth something in a competitive, cost-minded world.

In the absence of such rigorous proof, it is very easy for those who are a bit skeptical concerning the usefulness of tests to conclude after a time that the program has not been worth while. For one thing, they see only the employees you actually got on the pay roll with the help of tests. They have no idea what those potential employees might have been like who would have been hired if the tests had not been used. Also, the employees whom you hire may be scattered over a broad territory, such that no individual supervisor has intimate contact with a very large proportion of them, so as to be able to arrive at any justifiable opinion about the adequacy of the selective process. Furthermore, the differences between good and less good employees do not show up overnight, but may be in question for a year or more while the new employee is finding his niche, and gradually coming to be recognized in terms of his true job competence. And finally,

as we have said, the improvement in selection will not be dramatic and startling, as it might be if we could offer the prospective employer a crystal ball.

Therefore, while we are personally convinced that tests can be of immediate use to you in many of your employment situations, nevertheless, if you want to use tests on that basis, you will have to accept them on faith, and you will have to assure the technical man who helps you that you are prepared to make use of them on that basis. Most experienced test technicians have had their fingers burned often enough by skeptics to be very conservative, unless you can give them reassurance of your fundamental appreciation of what you are asking them to do.

Summary.

We have now covered in a general way the basic principles of three of the techniques of so-called "scientific selection"—the weighted application blank, the planned interview, and the employment test. Some detail has been presented concerning certain aspects of these techniques; but it is really a point of view that we have been attempting to convey, rather than a mass of detail, and by way of summary, that point of view may be briefly restated.

That point of view is that the application of scientific principles to selecting people must be approached in exactly the same way that you approach your everyday engineering problems. You don't expect to perform magic; you don't have a wand that will build bridges, or a secret incantation that will bring out of the air the perfect way to process a new plastic.

You do have a set of principles and methods, and a body of technical knowledge; and you use them to do the job a little better today than it was done yesterday, and a little better again tomorrow. Looked at in this light, the selection techniques we have discussed are useful in improving our batting average in the selection of employees; and they can be put to use in the present period of rapid force expansion.

AIDS FOR ANALYZING HIGH-SPEED ACTION.

Many of the several methods of analyzing high-speed motion are classified in this abstract of an article prepared by E. M. Watson of the General Electric Lamp Development Laboratory, published in General Electric Review, October, 1941. In making estimates as to how a mechanism will perform, it is not always possible to forecast all of the effects of motion. To find out what is going on, some method of visual aid must be employed. Mr. Watson's article is intended to give the person of average interest in this field a view of its extent, and to facilitate the choice of equipment for studies of objects in motion.

During the last few years, a number of articles on high-speed photography, stroboscopes, etc., have been published, each dealing with a particular device, but no attempt seems to have been made to classify or relate the methods employed. Hence, in this article there will be presented a classification of the various principal methods and devices, and also a brief description of each.

The classification of means for analyzing motions that are too rapid for unaided visual observation is included as Table I. The column at the left lists various general types and arrangements of apparatus; the middle column outlines the manner in which investigations are made when the subject is

continuously lighted; and the column at the right applies to methods employing intermittent light on the subject.

In almost every setup the following points must be considered:

(1) Means must be devised for placing the image (with necessary sharpness and steadiness) on the medium where the exposure is to take place.

(2) Arrangements must be made for starting and stopping the exposure.

(3) Means must be devised for placing the subsequent exposures on recording material at the proper time and location to obtain the desired results.

Recognition of these requirements gives some idea of the method of accomplishment in each case.

Visual Observation.

Item I of Table I refers to the visual observation of repetitive phenomena, such as take place in the action of engines or of other devices where a specific motion is continually repeated.

When continuous light of sufficient intensity is reflected from or radiated by the subject that is to be observed, some type of shutter must be employed to pass light from the subject to the observer only at times when similar images will be seen.

Such a shutter control of the light that reaches the eye is provided in the Ashdown Rotoscope (London), shown in Figure 1. The observations are made through two slots in a tube which is revolved on its axis by a spring motor. These slots are fitted with vanes which further restrict the passage of light to only a very short interval out of each half revolution. By means of an adjusting knob, the observer can control the speed of the rotating tube and hence can view the performance of the subject at any one point in its operating cycle (by adjusting the rotoscope to synchronism with the subject) or throughout its cycle (by adjusting the rotoscope to a slightly different speed). Included also are speed-change gears which provide for a choice of any one of four basic speeds and thus give the device a considerable speed range of application.

Under conditions where existing continuous light reflected or radiated from the subject is not so bright as to overcome the contrasts introduced by an addition of intermittent light, the stroboscopic method of examination can be used to advantage.

Figure 2 shows the stroboscope that was used in the House of Magic demonstrations at the New York World's Fair. The tube mounted in the reflector is filled with neon. The power to operate the tube is taken from a condenser which quickly discharges during each flash, causing the light to be of very short duration. The necessary circuit is provided for recharging the condenser at sufficient speed to allow the flashes to take place at the rate of once for each revolution of the wheel, which is driven by a synchronous motor. The circuits used depend on how the equipment is to be employed.

When a particular point of an operating cycle is being studied, the flashes of light should be made to coincide with that point of the operating cycle, though the timing of the light may also be varied somewhat to bring other points of the cycle into view. Apparatus for this work can sometimes be constructed from equipment that is at hand, but in most cases it is more economical to purchase apparatus designed for the purpose.

Still Cameras.

Whenever the subject being investigated does not repeat its motion at all or not often enough to use a stroboscopic device, it is necessary to use some

PRINCIPAL METH

CLASSIFICATION	
I. Direct visual observation	
II. Still Cameras	
(a). Single-image	
(b). Multiple-image	
III. Motion-picture cameras	
(a). Cameras with intermi motion which allows film to re stationary during exposure. S limited by strength of intermi mechanism and film.	
(b). Cameras in which the fil transferred from spool to spoo continuous speed. Speed limite strength of film.	
(c). Cameras which operate at high speed that the film is not s enough to run unsupported. difficulty is overcome either by porting the film while in motion allowing it to remain stationary optically moving the image.	

TABLE I

AL METHODS FOR STUDYING PHENOMENA THAT ARE TOO FAST FOR UNAIDED VISUAL OBSERVATION

TION	SHUTTER METHOD Used where subjects radiate light of themselves or reflect utility light not used to determine exposure time. Exposure time is determined by shutter.	STROBOSCOPIC METHOD Used where other light does not materially interfere with stroboscopic light. Exposure time is determined by stroboscopic flash.
vation	Visually observing through a shutter the action of devices that perform repetitive cycles.	Visually observing without optical apparatus the action of devices that perform repetitive cycles.
	Camera with shutter which will give a single exposure of adequate shortness of time.	Camera with its shutter open during a single stroboscopic flash.
	Camera with continuously open shutter, and exposure repeated at short intervals by means of moving perforated disk or other special light-interrupting device.	Camera with its shutter continuously open during several stroboscopic flashes.
neras th int..rmittent film to remain xposure. Speed of intermittent	Ordinary motion-picture camera which may be operated up to about 150 frames per second.	Ordinary motion-picture camera fitted with stroboscope which may be operated in synchronism with film.
hich the film is ool to spool at peed limited by	Special cameras in which exposures are controlled by a shutter, and images are moved with the film by means of optical devices, such as prisms or mirrors that are used in addition to the objective lens. Most common operating speed, 1000 frames per second. Maximum speed about 6000 to 7000 frames per second.	Special cameras in which the film is moved past the objective lens, and synchronized stroboscopic flashes are used to produce exposures that are so short that no appreciable motion of the image on the film can be detected.
operate at such ilm is not strong supported. This e either by sup- in motion or by stationary and image.	Special cameras of various types of construction where exposures are controlled by shutters. Maximum speed thus far attained about 120,000 exposures per second for 1000 exposures.	Special cameras for taking pictures of phenomena such as lightning, etc., which are somewhat stroboscopic of themselves.

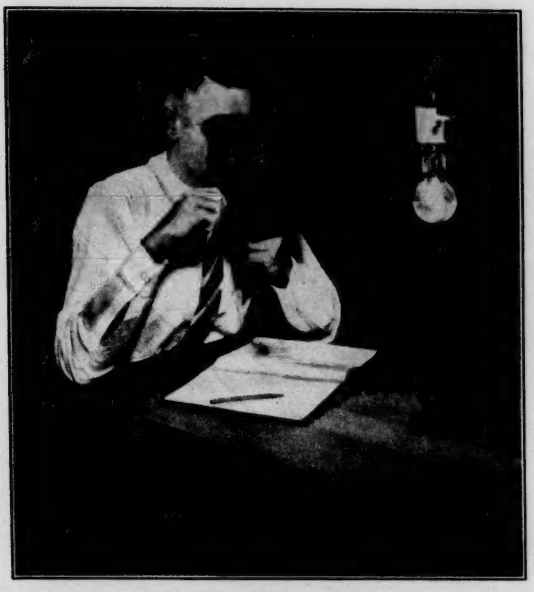


FIGURE 1.—ASHDOWN ROTOSCOPE FOR MAKING OBSERVATIONS UNDER CONDITIONS WHERE LIGHT FROM SUBJECT BEING OBSERVED PREVENTS THE USE OF ORDINARY STROBOSCOPIC METHODS.

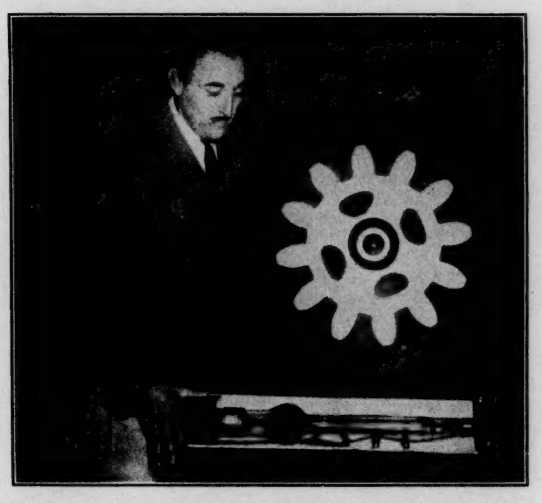


FIGURE 2.—STROBOSCOPIC EQUIPMENT USED FOR DEMONSTRATION PURPOSES. IN THE NORMAL OPERATING POSITION, THE TUBE AND REFLECTOR ARE TURNED TOWARD THE WHEEL. THE USEFUL LIGHT FROM THE STROBOSCOPIC TUBES ORIGINATES EITHER IN MERCURY VAPOR OR RARE GASES.

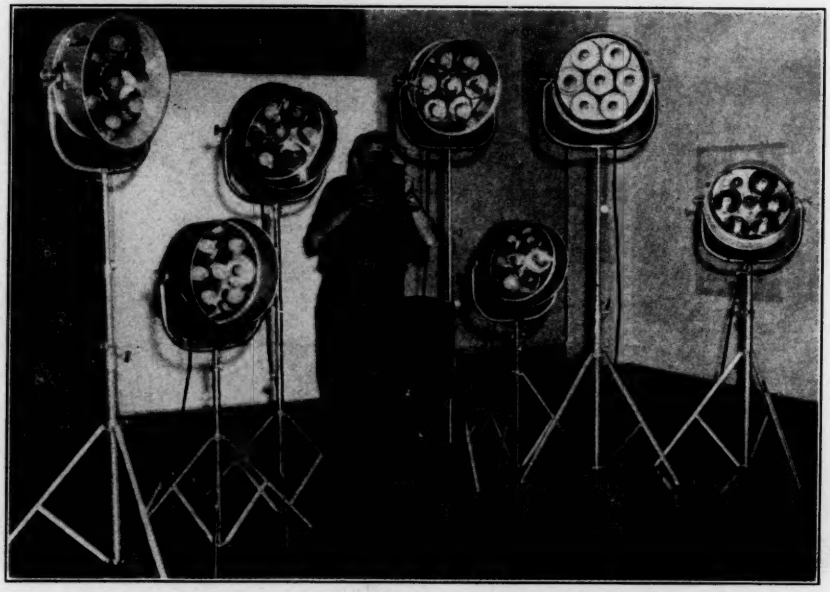


FIGURE 3.—CAMERA AND LIGHTS WITH SYNCHRONIZING EQUIPMENT FOR OBTAINING SINGLE EXPOSURES AT HIGH SHUTTER SPEEDS.

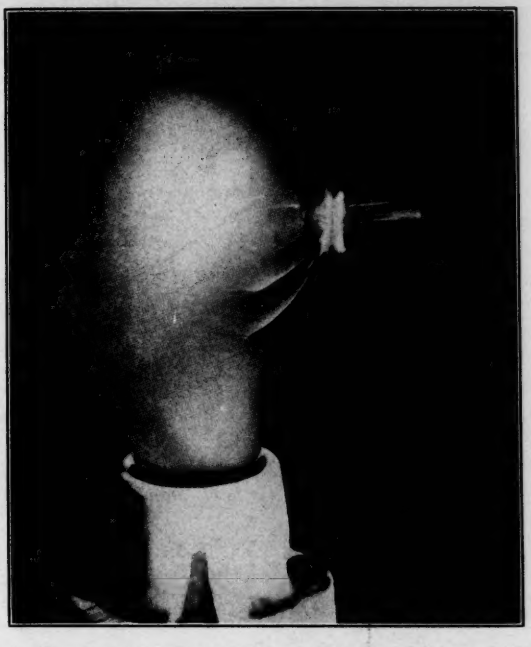


FIGURE 4.—PHOTOGRAPH OF A .30-CALIBER BULLET (VELOCITY 2700 FEET PER SECOND) STRIKING AN ELECTRIC LAMP BULB. NOTE THAT THE CRACKS IN THE GLASS TRAVEL FASTER THAN THE BULLET. AN EXPOSURE OF LESS THAN 2 x 10-6 SECONDS IS REQUIRED TO "STOP" THE BULLET WITHOUT BLUR AS SHOWN IN THIS PICTURE.

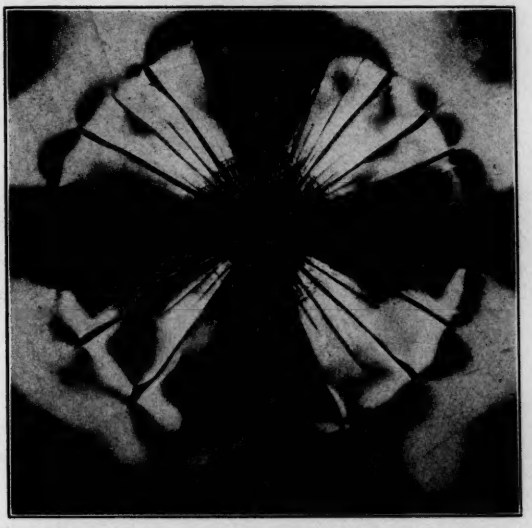


FIGURE 5.—A MICROSECOND SILHOUETTE PHOTOGRAPH TAKEN WITH STROBOSCOPIC POLARIZED LIGHT TO SHOW THE STRESS PATTERN DURING THE GROWTH OF THE CRACKS IN A GLASS PLATE WHEN VIOLENTLY BROKEN. THE CRACK VELOCITY IS 5000 FEET PER SECOND. IT IS MEASURED BY TAKING TWO PHOTOGRAPHS SPACED IN TIME BY 15 MICROSECONDS.

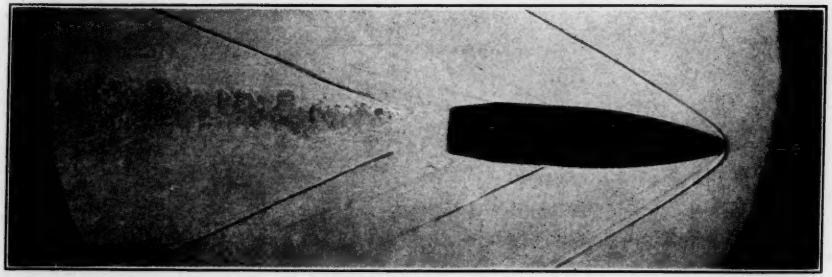


FIGURE 6.—A SINGLE-FLASH SILHOUETTE PICTURE OF A .50-CALIBER PROJECTILE IN FLIGHT.

FIGURE 7.—HIGH-SPEED MULTIPLE-EXPOSURE PHOTOGRAPH OF ARC INTERRUPTION, SHOWING SUCCESSIVE STAGES OF THE ARC AT INTERVALS OF ABOUT 1/800 OF A SECOND.

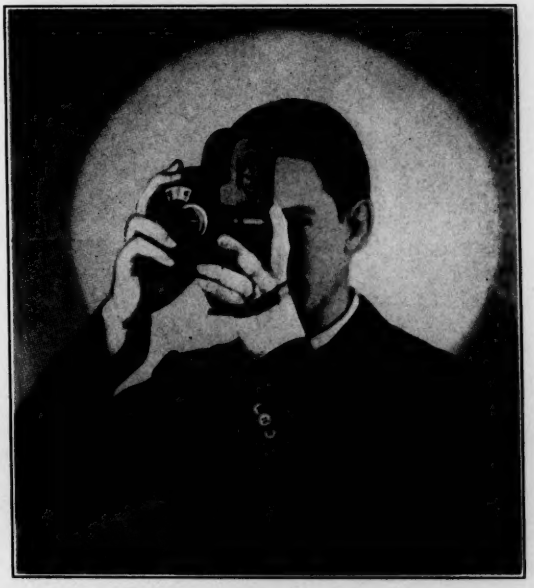


FIGURE 8.—BELL AND HOWELL SUPER-SPEED CAMERA IN WHICH THE FILM MOVES INTERMITTENTLY. THIS CAMERA IS SOMETIMES CALLED THE GOLF-STROKE-ANALYSIS CAMERA.

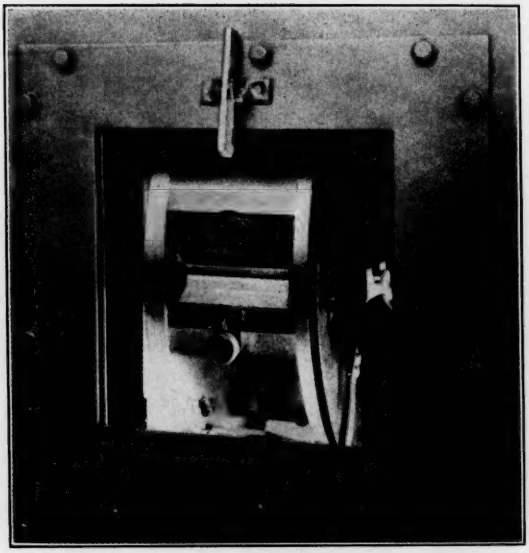


FIGURE 9.—FRONT VIEW OF HIGH-SPEED PINHOLE CAMERA THAT CAN TAKE PICTURES AT THE RATE OF 120,000 PER SECOND.

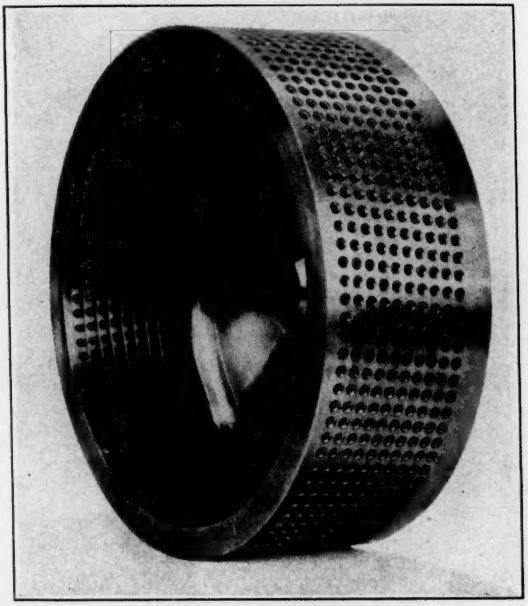


FIGURE 10.—ROTOR WITH PINHOLE LENSES WHICH SUPPORTS THE FILM IN THE CAMERA SHOWN IN FIGURE 14.

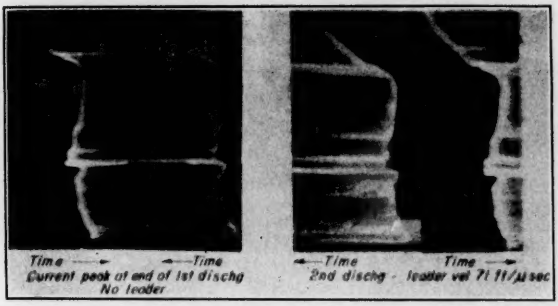


FIGURE 11.—HIGH-SPEED BOYS CAMERA PHOTOGRAPHS OF MULTIPLE-STROKE LIGHTNING TO THE EMPIRE STATE BUILDING TOWER.

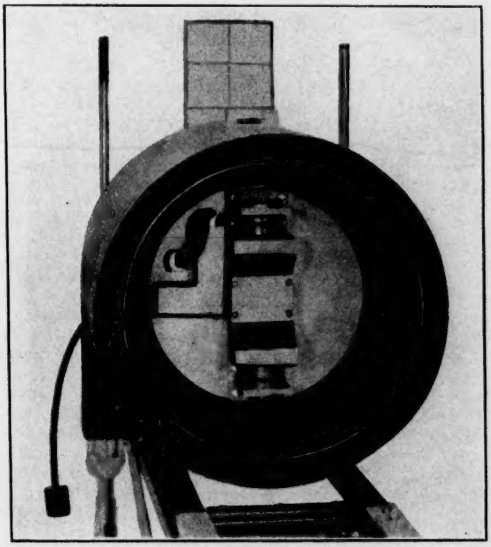


FIGURE 12.—INTERIOR OF THE HIGH-SPEED BOYS CAMERA, SHOWING THE STATIONARY-FILM CYLINDER AND THE ROTATING LENSES AND PRISMS.

form of photography for quickly recording the action for later study. When complications are not great, still cameras can be used.

Single Images.

When it is not necessary to know what happens before and after a given instant, a single exposure on a stationary film may suffice. In Table I, this condition is listed as II(a). For many applications much can be accomplished with still cameras, particularly if the camera's shutter is capable of a speed of the order of 1/1000 of a second.

Figure 3 shows a setup used by Jack Price in taking single shots at very high shutter speeds. Attached to the camera is a synchronizer which makes possible the electrical signal that the opening in the curtain shutter is approaching the film. This signal is in advance of the uncovering of the film by an amount which will allow the photoflash lamps to reach the desired plateau of light intensity by the time the exposure is started. The synchronizer reduces the voltage on the grid of a thyratron tube to a point where the tube is made conducting, thus causing the lamps to be set off. The lamps in each cluster are connected in series. The leads from the clusters are plugged into the box containing the thyratron tube, etc., and the usual arrangement is to have them in parallel.

Single-shot exposures may also be taken by stroboscopic light, examples of which are shown in Figures 4 and 5. These stroboscopic pictures were obtained from Dr. Harold E. Edgerton, K. J. Germeshausen, and H. E. Grier, who have very ably used the technique of flash photography at the Massachusetts Institute of Technology. The apparatus and methods have been widely described.[1]

Even with a still film or plate and no camera, instructive silhouette photographs can often be taken by interposing the moving object between the stroboscopic light source and the sensitized material. For example, in the study of the flight of projectiles fired from a gun, the compression and rarefaction of the air due to the sound wave will refract the light, causing it to show in a photograph. Figure 6 shows a .50-calibre projectile traveling about 2400 feet per second, as photographed by Dr. A. C. Charters of The Aberdeen Proving Ground (Md.) The sound wave from the bow and stern may be seen, as well as the wave from the grooves caused by the rifling. The turbulence of the air in the path just traversed by the projectile can also be seen.

Multiple Images.

When the action to be studied moves across the field of view, multiple exposures on a single plate can be used to record what takes place. In Tabel I this condition is listed as II(b). The photograph in Figure 7, taken by Otto Schurig, of an arc in a contactor,[2] is an example of an action recorded by multiple-image photography. A disk with a series of radial slots near its periphery was revolved before the still camera lens during the time the arc took place. The various positions of the arc were recorded when the slots in the disk successively uncovered the lens. The difference in brightness of the various images of the arc is caused by their being taken at various points on the alternating-current cycle.

[1] An extensive bibliography on high-speed photography is included in the recent book *Flash* by H. E. Edgerton and J. R. Killian, Jr.

[2] "The Performance of Contactors as Circuit Interrupting Devices," by B. W. Jones and O. R. Schurig, General Electric Review, vol. 39, p. 78, February 1936.

Motion-picture Cameras.

When a single picture is insufficient and the motion occupies approximately the same area, causing multiple images to overlap and to be confused, one must resort to motion pictures. Motion pictures taken at speeds in excess of the regular projection speed will, when projected, show the action in slow motion. In Table I motion pictures are listed as III.

Intermittent Film Movement.

If the difference between taking speed and projecting speed need not be very great, an intermittent camera III(a) would be suitable. In this type of camera the film is drawn from the supply reel and wound on the takeup reel at constant speed. However, film is stationary adjacent to the lens aperature when each exposure is made. It is advanced intermittently past the aperture for the exposure of each successive frame, and the light through the optical system is interrupted during the motion of the film. Figure 8 shows a Bell and Howell super-speed 16-millimeter camera which will operate at about 128 frames per second or eight times the normal projecting speed. Most of the slow-motion pictures of athletic events, etc., shown in theaters are taken at about this number of frames per second.

Continuous Film Movement.

When it is desired to operate at a picture frequency in excess of that attained with an intermittent camera, a camera in which the film moves continuously without stopping must be employed. In the class of cameras designated as III(b) in Table I, the film is passed from one spool to another at a constant speed, once the desired speed has been attained. The images are either placed on the film almost instantaneously by means of stroboscopic light or allowed to travel with the film for a short distance by means of an optical system.

The stroboscopic camera of this type is very simple in construction, because its optical system consists of only an ordinary lens which is arranged to focus the image on the film as it passes. The stroboscopic exposures are usually so short that the motion of the image on the film is less than the dimensions of the optical errors of the lens (circles of confusion), and therefore the motion of the image is not noticed. This method has the advantage of stopping very fast motion which would blur the image on the film if continuous light and a camera which allowed a longer period of exposure were used. Another advantage of this type of camera is that the light is on the subject only while a picture is being taken and, therefore, has less heating effect than if it were left on continuously.

Cameras that employ an optical system to move the image with the film can be used to advantage in photographing subjects which radiate continuous illumination. Various methods have been used in constructing cameras of this type. The Jenkens camera displayed in the Smithsonian Institution at Washington (D. C.) employs a ring of lenses which move with the film. The Eastman high-speed cameras employ a revolving glass plate which moves the image along with the film. The same effect is accomplished in the Zeiss camera by means of mirrors. The top speed of all these cameras which use spooled film is limited by the rate at which the camera can pass film from one spool to another without serious damage to the film.

At the present time, the practical upper limit of film speed seems to be about 100 miles per hour. Using full frames of 16-millimeter film, this speed would correspond to a picture frequency of 6000 to 7000 frames per second. When several pictures are placed in the area regularly occupied by

one picture, it is possible to increase further the picture frequency. This usually cannot be done, without major alterations, in a camera having an optical system that moves the image with the film, but it is not difficult to accomplish in a stroboscopic camera. To make the change in the latter camera, about all that is necessary is a mask to limit the field on the film and a means of producing the stroboscopic flashes at the desired increased frequency. Pictures taken under these conditions and intended to be projected as motion pictures should be re-photographed with an animation camera, enlarging to full-frame size the section of the film on which the desired action took place.

Mechanically Supported Rotating Film.

When there is required a picture frequency greater than that which can be obtained with the types of camera in which the film is passed from one spool to another, it is necessary to mount the film on a drum for support. This arrangement is listed as III(c) in Table I. The greatest speed so far known is that attained by D. C. Prince and W. K. Rankin who constructed a camera that will take 1000 pictures at rates up to 120,000 pictures per second.[3] A front view of this camera is shown in Figure 9 and the rotor in Figure 10. The film used is 4½ inches wide by 40 inches long and contains space for ten rows of images, each row consisting of 100 individual pictures. At maximum rotational speed, the length of the film is sufficient to record an event lasting 1/120 of a second, which is equal to one alternation of 60-cycle alternating current.

Cameras of this type are limited to the photography of phenomena which are complete in one revolution of the rotor, unless special precautions are taken to prevent interference from multiple exposures on the film or unless a high-speed shutter is used to block out the light except during the one revolution. Because of the very short exposure the subjects should be of very great brightness. Either black-and-white or color film can be used.

This camera was built to study the performance of high-speed switchgear, and when operated at the highest speed it is especially valuable in photographing arcs which are extinguished after one alternation. The film is held, by centrifugal force, on the inside of the rim of the rotor, with the emulsion away from the main shaft. The rotor is so constructed that it consists essentially of 1000 very small cameras having pinhole lenses. These pinholes correspond to the first zones of zone plates, and are of such size as to give the best image under the conditions in which they are used. The images are exposed progressively from one row to the next, until the tenth row is reached. This is followed by repetitions, beginning each time with the first row. The pictures may be printed on paper for examination in the same manner as is done in still photography. If it is desired to show them as a motion picture, it is necessary to photograph individual views with an animation camera in order to locate each picture properly in the desired frame area.

Mechanically Supported Stationary Film.

Instead of causing the film to rotate, it may be placed in a stationary drum and the light caused to sweep over it if the objects to be photographed give off light sufficiently stroboscopic to permit intelligible images to be

[3] "A 120,000-exposure-per second Camera," by D. C. Prince and W. K. Rankin, General Electric Review, vol. 42, p. 391, September 1939.

obtained. Such devices have been used by Dr. K. B. McEachron, J. H. Hagenguth, and C. J. Kettler for studying lightning discharges.[4]

In addition to facilitating the study of the formation and history of lightning strokes, cameras of this Boys type may be used to study the phenomena associated with the start of sparks and arcs and also the entire history of a spark or arc. Two such designs of cameras have been built, known as the low-speed and high-speed types. A record made with the high-speed camera is shown in Figure 11. Figure 12 shows the end of the camera in which the film cylinder is located. The housings for the two objective lenses and the two prisms may also be seen. The rotation of these causes the light to sweep along the film.

This type of camera will give a continuous record of the propagation of a spark during its formation and the change in intensity after it is formed. The maximum power of resolution so far obtained is 11/1,000,000 of a second or 11 μs per millimeter of the film. By enlarging the pictures obtained, shorter times can be investigated. Speeds of propagation of lightning strokes as high as 65,000 miles per second have been measured.

Conclusions.

In any kind of high-speed photography, all the limitations of ordinary photography are encountered plus some special restrictions imposed by the high speed. As types of cameras are changed to obtain increased speed, compromises in image quality and in exposure must be made. In the operation of an intermittent camera of the type mentioned as III(a) in Table I, the film is stationary while the exposures are made. This allows the best quality of image to be obtained from the lenses, a variety of which may be used. Only a moderate amount of light is needed, and both black-and-white and color film can be used.

At high speeds where a camera of the type designated as III(b) in Table I is used, in which the film is passed from one spool to another without intermittent motion, it is necessary to increase the intensity of the illumination because the time of exposure is shortened. It is fortunate, however, that, owing to the deviation from the reciprocity law, the intensity of illumination does not have to be increased quite in proportion to the reduction in exposure time. Focal length and width of aperture of objective lenses are often limited for cameras which require an optical device for moving the image with the film.

Of the two general types of cameras, the stroboscopic type will usually give the better quality of image. With it there is no restriction on the focal length of the lens or the wideness of the aperture. When the camera is run at regular speed, there are only minor variations—such as vibration, etc.—which might cause the film to take a slightly different position than was intended. The lighting requires the most attention, since it must be of extremely short flashes for which special electrical equipment is required. The stroboscopic light thus produced is usually quite actinic, which simplifies the film requirements for black-and-white photography. If color photographs are to be made, attention must be paid also to having proper color balance.

For cameras in which the images are moved optically with the films, the lighting is simple but the lens and other camera requirements are more

[4] "Lightning to Empire State Building," by K. B. McEachron, Jour. Franklin Inst., vol. 227, pp. 156-159, February 1939.

"Lightning Recording Instruments," Part II, by J. H. Hagenguth, General Electric Review, vol. 43, p. 248, June 1940.

"Cameras for Lightning Studies," by C. J. Kettler, Phototechnique, vol. 2, p. 38, May 1940.

complicated. For most purposes, the light from incandescent lamps, the sun, or the subject itself will be adequate.

Among the optical systems of these cameras are some in which the motion of the image does not follow the film exactly, and in which the optical distance through the system varies slightly during exposure. These two factors contribute to the conditions that prevent high-speed pictures being as good as those obtained with the same lenses when no optical system for moving the image is employed. The loss in quality in most cases is about the same as that occasioned in changing from 16-millimeter film to 8-millimeter film when running at normal speed. The part of the optical system for moving the image limits the use of lenses to those of the longer focal lengths, restricts the amount of light that can be passed by increasing the lens apertures, and causes some loss of light en route.

The speed range of high-speed photography is continuous. At one extreme there is the example of the telephone companies' photographing of call counters. Here the visual observation period can be very long but the detail is necessarily great. By these pictures, errors can be checked. The other extreme is the camera for studying lightning flashes. Here the detail to be observed may not be great but the visual observation period is very short.

There is opportunity in high-speed photography for anyone having only modest equipment, but many of the applications require very expensive equipment which has little versatility.

PROBABILITY GRAPH PAPER AND ITS ENGINEERING APPLICATIONS.

Statistical method summarizes and gives character to raw quantitative data, replacing the mass of data by relatively few quantities adequately representative of the whole. H. Rissik, prolific author of articles on statistical methods, considers "probability graph paper" a greater practical aid to the wide use of statistical methods than even the modern calculating machine. His article is taken from the October 24 and October 31, 1941 issue of The Engineer.

Both the British Standards Institution and its counterpart in America, the American Standards Association, are actively contributing to the common war effort of the two great democracies by issuing so-called emergency standard specifications to meet the peculiar needs of a wartime manufacturing program. In this connection the request made to the American Standards Association at the end of last year by the United States War Department for the initiation of a scheme for standardizing the application of statistical methods to the quality control of materials and manufactured products, and the subsequent issue by that standardizing authority of two war emergency specifications dealing with this subject,[1] serve to remind us that the development of methods for the scientific control of product quality is a matter of vital importance to our war industries.

In a recent article,[2] entitled "Statistical Methods in Engineering Practice,"

[1] American Defense Emergency Standards, Nos. Z1.1, 1941; Guide for Quality Control; and Z1.2, 1941; Control Chart Method of Analyzing Data.

[2] This article was published in The Engineer at the end of 1940, and appeared in four parts, viz.:

Part I: Fundamental Aspects of Statistical Technique (November 29th).
Part II: Quality Control in Production Engineering (December 6th and 13th).
Part III: Quality Standards in Purchasing Specifications (December 20th).
Part IV: Sampling Inspection in the Control and Standardization of Quality (December 27th).

the author gave a general account of the practical applications of statistical science to industrial engineering. In one form or another such methods have been in use in this country for a number of years in various branches of industry, notably in electric lamp manufacture, in the sampling of coal, and in the testing of textile fabrics. From the engineering standpoint, however, and particularly where mass production engineering is concerned, by far the most important use of statistical methods lies in a field where it appears to have as yet received but scant attention—the setting up of tolerance limits whose transgression at once indicates that the manufacturing process is becoming uncontrolled, *i.e.*, that unless action is taken the process will sooner or later turn out a defective product.

This neglect is all the more unfortunate in that the application of statistical methods to the quality control of a manufactured product involves quite a simple technique, no matter how abstruse or seemingly complicated may be the mathematics on which that technique is ultimately based. The trouble has been that in the past the statistician has not made it sufficiently clear to the engineer that an understanding of statistical theory, both as a science and a philosophy, is altogether unnecessary to the practical application of statistical methods. Such methods are absolutely within the competence of an up-to-date inspection organization, which in any case is a *sine qua non* where mass production engineering is concerned, and there is therefore no reason why they should not be very widely applied. Especially is this so nowadays, when calculating machines are generally available for lightening the continuous task of computation necessary to the statistical condensation of numerical data obtained from repetitive manufacturing processes.

As a practical aid to the wider application of statistical methods to the control of product quality, an even greater boon than the modern calculating machine is the special type of graph paper known as "probability paper." It is not so very long ago—two or three decades at most—since engineers came to realize the value of logarithmic graph paper as a rapid means of solving certain types of problems. Just as this class of graph paper is known in both the "semi-log" and "log-log" forms, each of which has its own characteristic advantages, so, too, is the newer probability graph paper nowadays available in either the "arithmetic" or the "logarithmic" form. Before describing the way in which probability paper can be put to practical engineering use, however, it is necessary to indicate briefly the statistical background to such a problem as that of quality control, a problem which this latest type of graph paper enables the engineer to solve with a minimum of computational effort.

The Statistical Treatment of Quantitative Data.

One of the outstanding features of statistical technique and, in fact, the main outstanding feature where engineering applications are concerned, is the basis which it provides for a systematic presentation and analysis of quantitative data. In the words of Professor R. A. Fisher, our leading authority in the field of biometrics (*i.e.*, theoretical statistics applied to biology): "A mass of data which by its mere bulk may be incapable of entering the mind is to be replaced by relatively few quantities which shall adequately represent the whole; or which, in other words, shall contain as much as possible—ideally the whole—of the relevant information contained in the original data." Statistical method, then, is concerned primarily with summarizing and giving character to quantitative data. It serves to make raw data informative, so that intelligent judgments may be passed upon them, by organizing, classifying and condensing them in a systematic manner.

The first step in systematizing quantitative data presented in the form of a set of unorganized numerical values, for example, a set of observed values of some measurable variable (Table I), is to arrange them in ascending order of magnitude. Such an arrangement is termed an ungrouped fre-

TABLE I.—TENSILE STRENGTH IN POUNDS PER SQUARE INCH OF EXPERIMENTAL DIE CASTING ALLOY AS DETERMINED FROM TEST PIECES TAKEN OUT OF NINETY-FIVE CASTINGS.

44,000	48,100	47,300	46,900	43,100
48,700	48,100	47,300	41,800	40,500
45,600	41,500	39,700	49,400	45,900
46,500	51,000	48,600	48,600	41,500
46,000	48,000	44,200	45,900	43,700
41,300	48,100	42,600	44,100	43,300
41,200	44,300	43,500	40,100	44,200
49,100	45,400	40,100	47,400	43,000
43,800	46,000	43,200	44,800	49,100
48,800	47,800	46,700	46,900	45,000
46,100	45,100	44,400	46,300	48,200
46,000	48,000	44,300	47,000	42,700
40,100	46,300	46,500	50,100	47,200
48,100	47,000	49,100	44,200	44,000
41,200	44,700	47,100	49,000	46,900
43,700	46,500	48,500	47,200	45,100
49,800	47,300	44,300	46,100	46,500
39,700	44,500	44,900	42,600	49,400
49,400	48,000	51,500	45,400	50,700

quency distribution and is often of value in the initial stages of analysis, for it shows at a glance the maximum, minimum and median (*i.e.*, middlemost) values of the variable (Table II). A closer examination of this organized set of values reveals a tendency for certain individual values or, more generally, for values lying within certain ranges, to occur more frequently than others—hence the term "frequency distribution," applied to such an arrangement.

This immediately suggests the next step in systematizing the raw data, that of classification, which consists in grouping the organized set of values into a number of successive classes, each class representing a definite range in magnitude of the observed variable. Such an arrangement is termed a grouped frequency distribution, and shows at a glance the frequency of occurrence of the observed values grouped together in any class (Table II—Horizontal Divisions). The interval, along the scale of measurement, occupied by each class is termed a cell. Each cell is in practice defined by the magnitude of the variable coinciding with the mid-point rather than with either of the two boundaries of the cell. The range of magnitudes lying between the cell boundaries (*i.e.*, between the lower and upper limits of magnitude of the variable within which lie the group of values pertaining to that particular class) is termed the cell interval. It is customary to make all the cell intervals the same, and to choose the cell boundaries halfway between two possible values of the variable.[3]

[3] For example, if the observations are recorded to the nearest ten units of measurement, the cell boundaries will have numerical values whose last digit is in each case 5; again, if the observed values are taken to the nearest 0.001, then the cell boundaries should be multiples of 0.0005. In the case of Tables II and III, the common cell interval is 1500 pounds per square inch and the cell boundaries have values whose last two digits are 50.

TABLE II.—ORIGINAL DATA OF TABLE I PRESENTED AS A FREQUENCY DISTRIBUTION (GROUPING IS INDICATED BY THE HORIZONTAL DIVISIONS).

39,700	43,300	45,100	46,900	48,200
39,700	43,500	45,100	46,900	48,500
	43,700	45,400	47,000	48,600
40,100	43,700	45,400	47,000	48,600
40,100	43,800	45,600	47,100	48,700
40,100	44,000		47,200	
40,500	44,000	45,900	47,200	48,800
41,200	44,100	45,900		49,000
41,200	44,200	46,000	47,300	49,100
	44,200	46,000	47,300	49,100
41,300	44,200	46,000	47,300	49,100
41,500		46,100	47,400	49,400
41,500	44,300	46,100	47,800	49,400
41,800	44,300	46,300	48,000	49,400
42,600	44,300	46,300	48,000	49,800
42,600	44,400	46,500	48,000	50,100
42,700	44,500	46,500	48,100	
	44,700	46,500	48,100	50,700
43,000	44,800	46,500	48,100	51,000
43,100	44,900	46,700	48,100	51,500
43,200	45,000	46,900		

Minimum = 39,700 Median = 46,000 Maximum = 51,500

The final step in systematizing the original data follows almost automatically from an examination of the grouped frequency distribution. It consists in condensing the detailed information contained therein by treating all observed values lying in any cell as having the same magnitude, viz., the particular value of the variable corresponding to the cell mid-point. The grouped frequency distribution is thus reduced to a simple frequency tabulation which gives the relationship between a relatively small number of equally spaced values of the variable x—the successive cell mid-points—and the frequencies with which they occur (Table III). The number of observations grouped together in any cell is termed the cell frequency and is denoted by f; while their summation Σf over all the cells of the frequency distribution—that is, the total number N of the observed values of the variable x—is the total frequency.

The number of cells into which any given frequency distribution should be subdivided is largely a matter of judgment and its choice must be guided by the following considerations:

(*a*) The number of cells should be such that one can treat all the observations assigned to any cell, without serious error, as if their values were equal to that value corresponding to the cell mid-point.

(*b*) A large number of cells tends to confuse the general picture of a frequency distribution and to emphasize sampling fluctuations.

(*c*) Too small a number of cells generally leads to appreciable inaccuracy in subsequent statistical computation, arising from the systematic error due to grouping introduced in accordance with (*a*) above.

Experience goes to show that these three conditions will generally be met if the number of cells lies between 10 and 20.

For some purposes the number of observations having a value less than, or more than, a given value of the variable is of interest. This consideration leads to the formation of a so-called cumulative frequency table, which

records the accumulated frequency of the several cells up to successive cell boundaries (Table III). Such a table is built up from the tabulation of absolute frequencies f by successively adding the individual cell frequencies $f_1, f_2, f_3 \ldots f_x$, and entering the cumulating sums f_1, f_1+f_2, $f_1+f_2+f_3$, &c. opposite the x values of the corresponding cell boundaries. The cumulative frequency Σf for any cell is thus the total frequency up to the upper boundary of that cell. It is, in effect, the number of observed values of the variable x whose magnitude is less than the value of corresponding to the upper cell boundary.

TABLE III.—FREQUENCY TABULATION OF THE ORIGINAL DATA AS PRESENTED IN TABLE II.

Cell No.	Cell mid-point.	Absolute frequency.		Cell bound'y.	Cumulative frequency.	
		f.	%		Σf.	%
				38,250	0	0
1	39,000	2	2·1			
				39,750	2	2·1
2	40,500	6	6·3			
				41,250	8	8·4
3	42,000	7	7·4			
				42,750	15	15·8
4	43,500	14	14·7			
				44,250	29	30·5
5	45,000	14	14·7			
				45,750	43	45·2
6	46,500	22	23·2			
				47,250	65	68·4
7	48,000	17	17·9			
				48,750	82	86·3
8	49,500	10	10·5			
				50,250	92	96·8
9	51,000	3	3·2			
				51,750	95	100

In the same way, by tabulating the differences between the total frequency N and these cumulative frequencies Σf, the corresponding "more than" table may be formed. Or it may be built up directly by cumulating the frequencies backwards from the end of the absolute frequency tabulation. In either case the cumulative frequencies so obtained are the total frequencies down to the lower boundaries of the successive cells, *i.e.*, each is the number of observed values of the variable x whose magnitude is more than the value of corresponding to the lower boundary of the cell in question.

A grouped frequency distribution or, to be precise, its corresponding frequency tabulation, may be represented graphically as a stepped diagram in which the height of each step is the cell frequency, the step width is the cell interval, and each successive step corresponds to a cell. Such a diagram is termed a histogram and is, in effect, a graph of absolute frequency f plotted against the variable x, but a graph whose discontinuities are an acknowledgment of the fact that the several values of x grouped together in each cell are not concentrated at the cell midpoint, but are in actuality spread out over the cell interval. Figure 1 (*a*) shows the histogram of the absolute frequency tabulation given in Table III.

The corresponding graph of the cumulative frequency tabulation ("less than" table) is shown in Figure 1 (*b*) and is known as an ogive. A little consideration will show that each ordinate of Figure 1 (*b*) is given by the sum of the areas of the rectangular steps of the histogram of Figure 1 (*a*) up to the cell boundary at which the ordinate is erected. In other words, the number of observed values of the variable x whose magnitude is less than some particular value x_m, say, is given by the area under the histogram up to the ordinate at $x = x_m$.

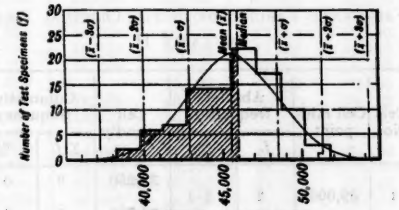


FIGURE 1.—HISTOGRAM AND OGIVE.

Generally speaking, if a frequency distribution can be represented by a smooth curve—known as a frequency curve—then the aggregate frequency in the range $x_a < x < x_b$ will be given by the area under the curve between the ordinates erected at $x = x_a$ and $x = x_b$. Since the total area under the curve is N, the total number of observations comprising the frequency distribution, it is seen that the relative frequency p (*i.e.*, the proportion of these observations) in the range $x_a < x < x_b$ is given simply by the ratio of the area between $x = x_a$ and $x = x_b$ to the total area under the curve. This unique property of frequency curves is the cornerstone of the statistical building which the engineer can construct for himself—a building as elegant as it is useful.

The Characteristics of a Frequency Distribution.

Although the grouped frequency distribution, whether in tabular or histographic form, constitutes the most systematic presentation of quantitative data, the information given therein may be still further condensed by making use of certain characteristics of the distribution. In general, three such characteristics are at once apparent from an inspection of the histogram, viz.:

(1) The tendency for the observations[4] to be distributed about some central value.

(2) The extent to which the observations are spread out on either side of this central value.

(3) The degree in which the distribution lacks symmetry with respect to the central value.

These three characteristics are defined respectively by the mean, the standard deviation, and the skewness of the frequency distribution. For reasons which will become apparent later, only the first two characteristics are of any importance in the engineering applications of statistical technique, so that there is no need here to discuss the skewness of a distribution.[5]

In the order of their importance from the point of view of a statistical analysis of quantitative data, the three measures of the central tendency of a frequency distribution are:

(*a*) *The Mode.*—This is the popular "average" of journalism and uninformed statistical pronouncements, epitomized in such a phrase as "the average man." It is simply that value which occurs most frequently, and its chief service is in characterizing a type. Mathematically it is very difficult to define, but it is at once evident from the general shape of a histogram. If a frequency distribution could be represented by a smooth curve, then the mode would be the abscissa of the highest point on the curve.

(*b*) *The Median.*—This may be defined as the middlemost or central value of the variable when the observations are arranged in order of magnitude (ungrouped frequency distribution). In other words, it is that value which is so situated that greater and smaller values occur with equal frequency. Considering the histogram of a frequency distribution, the median is the *x-value* of the ordinate which divides the area under the histogram into two equal parts. In general, the median of a frequency distribution is that value of the variable x for which the cumulative frequency Σf is half the total frequency N.

(*c*) *The Mean.*—This is the true average or arithmetic mean of the N observed values of x defined by

$$\bar{x}=\frac{1}{N}(x_1+x_2+x_3+\ldots+x_N)=\frac{1}{N}\sum_1^N x \qquad (1)$$

[4] The term "observation" is here rather loosely used to indicate what the statistician calls a "variate," that is, a numerical value connoting an individual magnitude of the variable whose frequency distribution is under consideration. This nomenclature will be adhered to in what follows.

[5] For a practical and altogether readable treatment of frequency distributions and their characteristics, see J. F. Kenney, "Mathematics of Statistics," Part I (Chapman and Hall, London, 1940). This is by far the best elementary work on the methodology of statistical science which has so far been published.

in the case of an ungrouped frequency distribution, and by

$$\bar{x}=\frac{1}{N}(f_1 x_1+f_2 x_2+f_3 x_3+ \ldots +f_k x_k)$$
$$=\frac{1}{N}\sum_1^k fx \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in the case of a grouped frequency distribution, for which f is the cell frequency, k the number of cells, x the value of each successive cell mid-point, and N is the total frequency, viz.,

$$N=f_1+f_2+f_3+ \ldots +f_k=\sum_1^k f \quad . \quad . \quad (3)$$

The mean of a frequency distribution is by far the most widely used measure of central tendency, for its alegbraic treatment is particularly easy, while, at the same time, it is relatively stable, *i.e.*, it is not much affected by sampling fluctuations.

A little consideration of equation (2) in conjunction with the histogram of Figure 1 (*a*) shows that the products $f_1 x_1$, $f_2 x_2$, . . . $f_k x_k$ are, in the language of mechanics, the "moments" of the cells about the zero axis $x=o$. Hence $\bar{x}$, the mean of the N observations, is the abscissa of the centroid of the histogram—a concept which makes a ready appeal to the engineering mind. A short cut to the computation of $\bar{x}$ in the case of a frequency tabulation such as that of Table III is to choose some arbitrary origin $x=x_o$ (preferably the mid-point of the middlemost cell, or of one of the two end cells) and to record the deviations of the successive values x_1 x_2, . . . x_k *from* x_o in terms of the number of cells rather than in terms of the actual variable x. If these successive deviations be denoted by t_1, t_2, . . . t_k and if the cell interval be I units, then for any particular cell $x=x_o+I\,t$. Equation (2) thus gives

$$\bar{x}=x_o+\frac{I}{N}\sum_1^k f\,t \quad . \quad . \quad . \quad . \quad (4)$$

The corresponding tabulation for the example of Table III is given in Table IV. The moments $f\,t$ are given in the fifth column of the table from which $\Sigma\, f\,t=44$. Also we have $N=\Sigma\, f=95$. With an arbitrary origin at $x_o=45{,}000$ and a cell interval $I=1500$, equation (4) thus gives

$$\bar{x}=45{,}000+\frac{1500}{95}(44)=45{,}695 \text{ lb. per sq. in.}$$

as the mean tensile strength of the ninety-five test specimens. The true mean as given by Table II and equation (1) is $\bar{x}=45{,}700$ pounds per square inch. The error due to grouping is in this case less than 0.01 per cent and is thus quite negligible in practice. (The median value is seen from Figure 1 (*b*) to be 46,060 pounds per square inch, which differs by a mere 0.13 per cent from the true value (46,000) given by Table II.)

The almost universal measure of the spread or dispersion of the observations about this central value is what is known as the standard deviation.

It is defined as the root-mean-square value of the deviations of the N observed values of x from their mean value $\bar{x}$ and is denoted by σ. Thus

$$\sigma = \sqrt{\left[\frac{1}{N}\left\{(x_1-\bar{x})^2+(x_2-\bar{x})^2+\ldots +(x_N-\bar{x})^2\right\}\right]} = \sqrt{\left[\frac{1}{N}\sum_1^N (x-\bar{x})^2\right]}$$
$$= \sqrt{\left[\left(\frac{1}{N}\sum_1^N x^2\right)-\bar{x}^2\right]} \quad . \quad . \quad . \quad (5)$$

in the case of an ungrouped frequency distribution, and

$$\sigma = \sqrt{\left[\frac{1}{N}\left\{f_1(x_1-\bar{x})^2+f_2(x_2-\bar{x})^2+\ldots +f_k(x_k-\bar{x})^2\right\}\right]} = \sqrt{\left[\frac{1}{N}\sum_1^k f(x-\bar{x})^2\right]}$$
$$= \sqrt{\left[\left(\frac{1}{N}\sum_1^k f x^2\right)-\bar{x}^2\right]} \quad . \quad . \quad . \quad . \quad (6)$$

in the case of a grouped frequency distribution with k cells, and total frequency $N = \Sigma f$ as given by (3). A little consideration of equation (6) in conjunction with the histogram of Figure 1 (a) will show that the products $f x^2$ are the "second moments" of the cells about the zero axis $x = o$; while the products $f (x-\bar{x})^2$ are the corresponding moments about an axis through the "centroid" $x = \bar{x}$. In the language of mechanics, therefore, the standard deviation σ is simply the "radius of gyration" of the frequency histogram—a concept which again makes a ready appeal to the engineering mind. The same computation short cut as was taken in the case of the mean value $\bar{x}$ is available in the calculation of the standard deviation. Using the nomenclature of equation (4), one finds from equation (6)

$$\sigma = \sqrt{\left[\left(\frac{I^2}{N} \cdot \sum_1^k f t^2\right)-(\bar{x}-x_o)^2\right]} \quad . \quad (7)$$

Referring to the frequency tabulation exemplified by Table III, the second moments $f t^2$ are given in the sixth column of Table IV, from which $\Sigma f t^2 = 356$. The deviation of the mean $\bar{x}$ from the arbitrary origin x_o is 695 pounds per square inch, so that equation (7) gives

$$\sigma = \sqrt{\left[\frac{(1500)^2}{95} \cdot 356-(695)^2\right]}$$
$$= 2820 \text{lb. per sq. in.}$$

TABLE IV.—COMPUTATION OF $\bar{x}$ AND σ.

Cell No.	x.	t.	f.	ft.	ft^2.
1	39,000	−4	2	− 8	32
2	40,500	−3	6	−18	54
3	42,000	−2	7	−14	28
4	43,500	−1	14	−14	14
5	x_0=45,000	0	14	0	0
6	46,500	1	22	22	22
7	48,000	2	17	34	68
8	49,500	3	10	30	90
9	51,000	4	3	12	48
Cell interval: I=1500		Totals:	Σf=95	Σft =44	Σft^2 =356

as the standard deviation of the ninety-five test specimens. The true standard deviation as given by Table II and equation (5) is $\sigma = 2785$ pounds per square inch. The error due to grouping is here less than 0.9 per cent and again is thus quite negligible in practice.

THE DISTRIBUTION PARAMETERS $\bar{x}$ AND σ AS APPLIED TO QUALITY CONTROL.

One of the functions of the engineer is to devise and perfect operations which, when carried out, will produce things that people want. His concern is thus primarily with quality characteristics—dimensions, tensile strength, hardness, color, finish, and such-like material attributes. At any rate, he must be able to make things having quality characteristics lying within tolerance ranges which he should be in a position to specify. From the purely engineering standpoint, he will regard the upper and lower limits of such a tolerance range simply as "manufacturing limits," that is to say, limits whose transgression immediately lands him with a defective and thus unwanted product. Such limits only enable the engineer to be wise after the event. They can serve merely as a gauge for products already made.

There is, however, another viewpoint from which the engineer can consider the tolerance ranges of his quality characteristics. This is the statistical point of view, from which the upper and lower limits of a specified tolerance range appear as "control limits." A range confined within such limits represents a target for the engineer to aim at, and the limits themselves can serve as a quality gauge for products not yet made. Such a statistical outlook involves the application of probability theory, whose implications have been discussed in a previous article.[6] To quote Shewhart, the pioneer of statistical technique as applied to the quality control of manufactured products:

"The engineer devises an operation and predicts that, if carried out, it will hit the target. But, since he does not have certain or perfect knowledge of facts and physical laws, he cannot be certain that a given operation will hit its target. The best that, in fact, he can hope to do is to know the *probability* of hitting the target. Here, then, is one fundamental way in which probability enters into everything that an engineer does."

[6] *Vide* H. Rissik, "Statistical Methods in Engineering Practice," Part I, The Engineer, November 29th, 1940, pages 341 and 342.

Quality, as measured on samples or individual batches of a manufactured product, is not constant, but varies from sample to sample, or from batch to batch. These variations, which arise from numerous causes, are separable into two broad classes according as to whether they are "significant" or "non-significant." A non-significant variation is one that merits no investigation; it is due to the operation of the laws of chance, whose calculus is the theory of probability. A significant variation, on the other hand, is one that indicates the presence in the production process of an assignable cause of variation in product quality whose operation, if allowed to continue, will sooner or later give rise to trouble. The manufacturer should therefore be interested in identifying and removing such assignable causes, while the engineer should be equally interested in providing him with the means of doing so. If and when this is accomplished, so that the remaining variations in product quality are due only to the operation of chance causes, the production process is said to be in a state of "statistical control."[7] The operational technique available to the engineer for recognizing the presence of assignable causes of variation in production processes

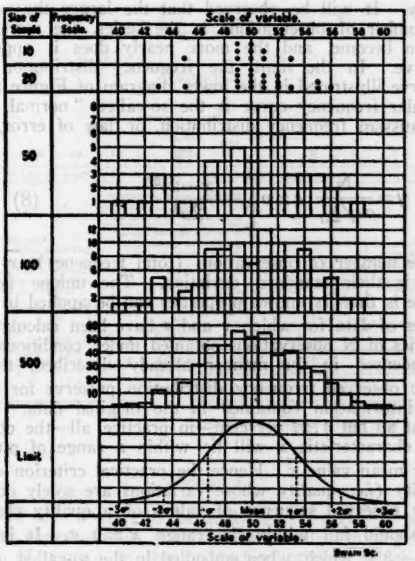


FIGURE 2.

is thus one based on statistical control theory; that is, upon a theory which "contributes the hypothesis that it is humanly possible to remove assignable causes of variability in the repetitive operations of the engineer until such operations approach a state of maximum control and obey the laws of

[7] For a discussion of this concept, see H. Rissik, *op. cit.*, Part II (*a*), The Engineer, December 6th, 1940, pages 357-359.

chance, a knowledge of which provides maximum assurance that the results of repeating an operation will fall within previously specified tolerance limits."

When such a state of statistical control has been reached, the variations in quality become predictable. Consider, for example, a representative series of quality observations obtained by inspection of a production process over a period of time during which, from the engineering standpoint at least, the variations in quality seem to have been reasonable, *i.e.*, they have not given rise to trouble in subsequent manufacture. What guarantee is there that henceforth the process will not give rise to trouble in the future? To answer this question it is necessary to subject the observed quality data to a statistical analysis. As has already been made clear, a statistical examination of such a series of observations reveals the existence of a certain relation between particular values of the quality characteristic and the frequencies with which they occur, a relation known as a frequency distribution. If the production process is in a state of statistical control this frequency distribution will appear as shown diagrammatically in Figure 2, where the series of observations is considered as a sample of the product quality. It will be observed that the larger the sample, *i.e.*, the greater the number of observations in the series, the more regular does the distribution become, and the more nearly does it approach towards a smooth curve. In the limit, the frequency distribution becomes the bell-shaped curve illustrated in the lower diagram of Figure 2.

This particular frequency curve is the so-called "normal curve," representing the Gaussian frequency distribution, or law of error, whose equation is

$$y=\frac{N}{\sigma\sqrt{2\pi}}\ exp\left[-\frac{(x-\bar{x})^2}{2\sigma^2}\right] \quad . \quad . \quad . \quad (8)$$

where N is the number of observations (total frequency), $\bar{x}$ is their mean value, and σ is their standard deviation. The unique feature of this frequency curve is that its known properties can be applied to a statistically controlled series of data for which $\bar{x}$ and σ have been calculated. In other words, if a series of N observations obtained under conditions of statistical control is condensed in the manner already described, the parameters $\bar{x}$ and σ of the observed frequency distribution preserve for future use all the statistical information contained in the original data. In particular, it is known that all but 0.27 per cent—in practice, all—the observed values of the quality characteristic x will lie within a range of plus and minus $3\ \sigma$ about their mean value $\bar{x}$. Hence the practical criterion of statistically controlled quality (*i.e.*, quality whose variations are solely due to chance) is that, in any observed sequence of values of a quality characteristic x, all the value should fall within the range $\bar{x} \pm 3\ \sigma$. It is these limits, $\bar{x}+3\ \sigma$ and $\bar{x}-3\ \sigma$, which, when embodied in the so-called quality control chart, enable the engineer to tell at a glance whether or not a production process is in a state of statistical control.[8]

The two principal uses of the quality control chart are illustrated by Figures 3 and 4, reproduced from the American Standards Association's recently issued specification "Guide of Quality Control."[9] Figure 3 shows

[8] For an elementary discussion of quality control charts and their construction, see H. Rissik, op. cit., Part II (*b*), The Engineer, December 13th, 1940, pages 372 and 373.

[9] American Defense Emergency Standard No. Z 1.1—1941. The corresponding specification, No. Z 1.2—1941, entitled "Control Chart Method of Analyzing Data," deals in detail with the construction of quality control charts.

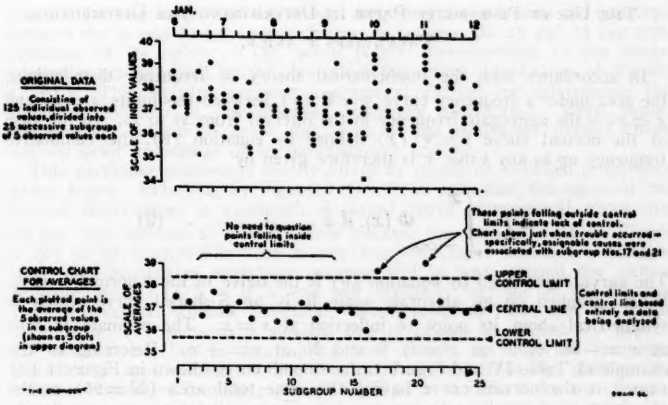

JAN.
ORIGINAL DATA
Consisting of 125 individual observed values, divided into 25 successive subgroups of 5 observed values each
SCALE OF INDIV. VALUES
No need to question points falling inside control limits
These points falling outside control limits indicate lack of control. Chart shows just when trouble occurred — specifically, assignable causes were associated with subgroup Nos. 17 and 21
CONTROL CHART FOR AVERAGES
Each plotted point is the average of the 5 observed values in a subgroup (shown as 5 dots in upper diagram)
SCALE OF AVERAGES
UPPER CONTROL LIMIT
CENTRAL LINE
LOWER CONTROL LIMIT
Control limits and central line based entirely on data being analyzed
SUBGROUP NUMBER

FIGURE 3.

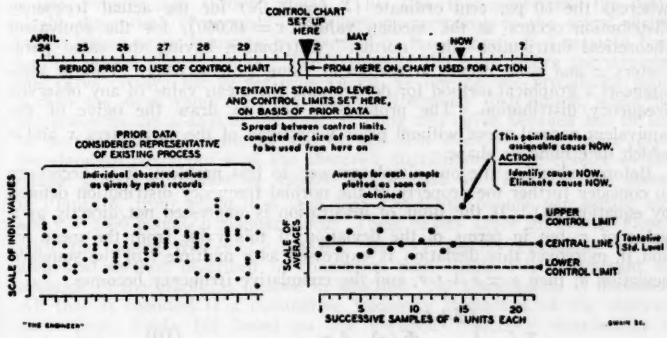

CONTROL CHART SET UP HERE
APRIL
MAY
NOW
PERIOD PRIOR TO USE OF CONTROL CHART
FROM HERE ON, CHART USED FOR ACTION
TENTATIVE STANDARD LEVEL AND CONTROL LIMITS SET HERE, ON BASIS OF PRIOR DATA
Spread between control limits computed for size of sample to be used from here on
PRIOR DATA CONSIDERED REPRESENTATIVE OF EXISTING PROCESS
Individual observed values as given by past records
Average for each sample plotted as soon as obtained
This point indicates assignable cause NOW.
ACTION
Identify cause NOW. Eliminate cause NOW.
SCALE OF INDIV. VALUES
SCALE OF AVERAGES
UPPER CONTROL LIMIT
CENTRAL LINE
Tentative Std. Level
LOWER CONTROL LIMIT
SUCCESSIVE SAMPLES OF n UNITS EACH

FIGURE 4.

the application of such a chart to the analysis of a series of observed values of some quality characteristic, with a view to determining whether there has been lack of control in the production process which yielded these values. In other words, it illustrates the use of the quality control chart as a means for the judgment of statistical control. Figure 4 indicates the features of such a chart when applied to the controlling of quality during production. Here the control limits $\bar{x} \pm 3\,\sigma$ form a basis for future action; they draw immediate attention to potential trouble. A control chart embodying only "manufacturing limits" cannot possibly do this; it can merely draw attention to actual trouble. In the latter case it is too late to do anything, but in the former case there is still time for taking action to eliminate the assignable cause before trouble actually develops.

The Use of Probability Paper in Determining the Distribution Parameters $\bar{x}$ and σ.

In accordance with the mathematical theory of frequency distributions, the area under a frequency curve $y = F(x)$ between the limits $x = x_a$ and $x = x_b$ is the aggregate frequency in the interval from x_a to x_b. In the case of the normal curve $y = \Phi(x)$ defined by equation (8), the cumulative frequency up to any value x is therefore given by

$$\Sigma f = \int_{-\infty}^{x} \Phi(x) . dx \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The curve represented by equation (9) is the ogive of the "normal" curve. When graphed on an algebraic scale it is an S-shaped curve which is symmetrical about its point of inflection at $x = \bar{x}$. The ordinate is zero at $x = -\infty$, ½ N at $x = \bar{x}$, [10] and N at $x = +\infty$. Referring to the example of Table IV and Figure 1, the smooth curve shown in Figure 1 (*a*) (*ante*) is the normal curve having the same total area (N = 95) as the actual histogram, the same mean value ($\bar{x} = 45{,}695$ lb. per square inch), and the same standard deviation ($\sigma = 2820$ lb. per square inch). The corresponding ogive is shown in Figure 1 (*b*) (*ante*). It will be observed that whereas the 50 per cent ordinate ($\Sigma f = ½$ N) for the actual frequency distribution occurs at the median value ($x = 46{,}060$), for the equivalent theoretical distribution—the "normal" distribution having the same parameters $\bar{x}$ *and* σ—it occurs at the mean value ($x = 45{,}695$). This at once suggests a graphical method for determining the mean value of any observed frequency distribution. The problem is how to draw the ogive of the equivalent normal curve without prior knowledge of the parameters $\bar{x}$ and σ which determine its shape.

Before indicating the one simple answer to this problem, it is necessary to consider further the property of the normal frequency distribution defined by equation (9). If the limit of integration is expressed not directly as a value of x, but in terms of the deviation of this value from the mean $\bar{x}$; and if, moreover this deviation is expressed as a multiple t of the standard deviation σ, then $x = \bar{x} + t\,\sigma$, and the cumulative frequency becomes

$$\Sigma f = \int_{-\infty}^{\bar{x}+t\,\sigma} \Phi(x) . dx \quad . \quad . \quad . \quad . \quad (10)$$

This integral has been evaluated and the following tabulation gives a few corresponding values of t and Σf:

t	Σf.
−3	0·001 N
−2	0·023 N
−1	0·159 N
0	0·500 N
+1	0·841 N
+2	0·977 N
+3	0·999 N

[10] *I.e.*, the median coincides with the mean. So also does the mode.

The standard deviation σ of the normal frequency curve is thus the intercept between the 16 and 50 per cent ordinates, or between the 50 and 84 per cent ordinates of its ogive. (The seven points corresponding to the above tabulation are indicated on the equivalent theoretical distribution of Figure 1 (*b*).) This, in turn, suggests a graphical method for determining the standard deviation of any observed frequency distribution. Here, again, the problem is how to draw the ogive of the equivalent normal curve without prior knowledge of its parameters $\bar{x}$ and σ.

This particular problem is readily solved by means of so-called probability graph paper. Referring to Figure 1 (*b*), it is seen that the ogive of the normal distribution is a smooth S-shaped curve symmetrical about the 50 per cent ordinate at $x = \bar{x}$. Now imagine the vertical scale of Figure 1 (*b*) to be stretched in such a way that this ogive becomes a straight line. The amount of stretching required will be least around the central ordinate, $p = (\Sigma f)/N = 0.5$, and will gradually increase as the distance from this central ordinate increases. Graph paper so ruled that the graph of equation (9) plots as a straight line is known as probability paper.[11] Its obvious use lies in determining how closely an observed frequency distribution approximates to the "normal" form. Thus by plotting the relative cumulative frequency $p = (\Sigma f)/N$ of a variable x for an observed distribution on probability paper, one can see at a glance how nearly the points lie on a straight line.

Having thus plotted a series of points (x, p), the next step is to draw a fair straight line through them. This line then represents the ogive of the theoretical ("normal") distribution equivalent to the actual distribution whose ogive in turn is represented by the succession of straight lines joining up the plotted points. The x-value of the point where the straight-line ogive crosses the 50 per cent ($p = 0.5$) line on the probability paper is then the mean value $\bar{x}$ of the observed frequency distribution, while the projection of the x-axis of the interval along this ogive between the 16 and 50 per cent lines (or the 50 and 84 per cent lines) on the paper gives the standard deviations σ of the observed distribution. The results of this simple graphical process as applied to the data of Table III are shown in Figure 5, from which it is seen that $\bar{x} = 45{,}700$ pounds per square inch and $\sigma = 2800$ pounds per square inch. These values agree sufficiently closely with the actual values ($\bar{x} = 45{,}695$ and $\sigma = 2820$), calculated by the analytical method described in connection with Table IV, to warrant the adoption of the graphical method in practice. No computation is necessary. All that is required is a cumulative frequency tabulation of the observed data (*e.g.*, Table III based on the grouped frequency distribution of Table II).

There is, however, one important exception to the practical application of the graphical determination of $\bar{x}$ and σ in the manner outlined above and illustrated by Figure 5. When the number of observations is less than 25, a frequency tabulation of the data is generally of little value from a presentation standpoint, and—what is more important—may lead to considerable grouping errors, particularly if $N < 10$. In such case it is preferable to plot the individual observations, after first having arranged them in ascending order of magnitude (ungrouped frequency distribution). The appropriate percentage value to be selected on the probability scale for each successive observation may be found from Table V. In general, the first observation in the sequence should be plotted on the "probability" line whose value is $50/N$ per cent, and the succeeding $(N - 1)$ observations at equal intervals of $100/N$ per cent.

[11] So called because the "normal" or Laplacian distribution occurs largely in probability theory. Certain discontinuous probability distributions, *e.g.*, Bernouilli's binomial and Poisson's exponential distributions, tend towards it as a limit.

TABLE V.—PERCENTAGE VALUES TO BE SELECTED ON PROBABILITY SCALE.

Observation No.	Available number of observations.								
	5.	6.	7.	8.	9.	10.	15.	20.	25.
1	10	8·3	7·1	6·25	5·6	5	3·3	2·5	2
2	30	25·0	21·4	18·75	16·7	15	10·0	7·5	6
3	50	41·7	35·7	31·25	27·8	25	16·7	12·5	10
4	70	58·3	50·0	43·75	38·9	35	23·3	17·5	14
5	90	75·0	64·3	56·25	50·0	45	30·0	22·5	18
6	—	91·7	78·6	68·75	61·1	55	36·7	27·5	22
7	—	—	92·9	81·25	72·2	65	43·3	32·5	26
8	—	—	—	93·75	83·3	75	50·0	37·5	30
9	—	—	—	—	94·4	85	56·7	42·5	34
10	—	—	—	—	—	95	63·3	47·5	38
11	—	—	—	—	—	—	70·0	52·5	42
12	—	—	—	—	—	—	76·7	57·5	46
13	—	—	—	—	—	—	83·3	62·5	50
14	—	—	—	—	—	—	90·0	67·5	54
15	—	—	—	—	—	—	96·7	72·5	58
16	—	—	—	—	—	—	—	77·5	62
17	—	—	—	—	—	—	—	82·5	66
18	—	—	—	—	—	—	—	87·5	70
19	—	—	—	—	—	—	—	92·5	74
20	—	—	—	—	—	—	—	97·5	78
21	—	—	—	—	—	—	—	—	82
22	—	—	—	—	—	—	—	—	88
23	—	—	—	—	—	—	—	—	90
24	—	—	—	—	—	—	—	—	94
25	—	—	—	—	—	—	—	—	98

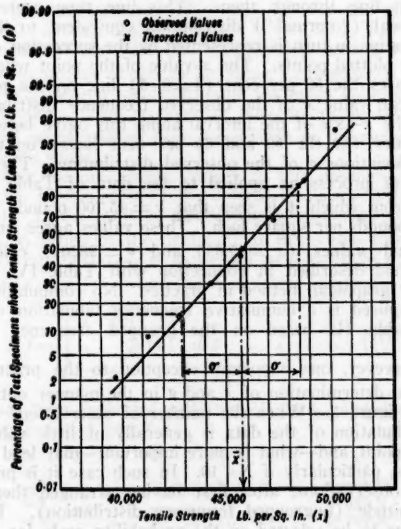


FIGURE 5.

Consider, by way of example, the following values of breakdown voltage obtained on ten samples of a certain paper insulation as used in cable manufacture:

980, 830, 1120, 845, 1020, 675, 910, 1225, 980, 1175.

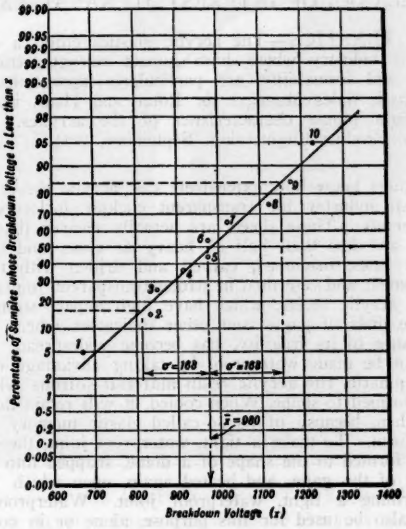


FIGURE 6.

When arranged as a frequency distribution they give:

Observation No.	Breakdown voltage.	Percentage value.
1	675	5
2	830	15
3	845	25
4	910	35
5	980	45
6	980	55
7	1020	65
8	1120	75
9	1175	85
10	1225	95.

The resultant plot on probability paper is shown in Figure 6. A straight line drawn through the ten points gives $\bar{x} = 980$ volts and $\sigma = 168$ volts, as compared with $\bar{x} = 976$ and $\sigma = 173.5$ by direct calculation, using equations (1) and (5) respectively. The extreme simplicity of this variant of the graphical method for determining $\bar{x}$ and σ is at once apparent.

The advantages attaching to the use of probability graph paper in the solution of statistical problems involving a determination of the mean and standard deviation of a series of quantitative data are so great that, in the author's opinion at any rate, the graphical method is nearly always to be preferred. Both the "arithmetic" and "logarithmic" forms are generally available, the latter being used when the variable is measured on a logarithmic scale (*e.g.*, loudness or attentuation measured in decibles).

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

ACRYLIC PLASTICS.—The acrylic plastics enjoy a considerable use in the aircraft industry where high impact strength, transparency, easy machinability and formability are particularly appreciated. Mr. D. S. Frederick, Plastic Sales Manager for Rohm and Haas, in this article describes the light piping characteristics of the acrylics. His article is reprinted from Product Engineering, September, 1941.

Many designers know how extensively cast acrylic sheets are being used by the aircraft industry for transparent cockpit inclosures, blisters and observation turrets. These sheets are actually clearer than glass, a great deal stronger and less than half as heavy as glass, and they can be cut with ordinary saws, machined, carved and drilled with the usual metal working equipment and cemented in strong transparent joints.

The use of acrylic sheets, which have high impact strength, to replace glass over the dials of gages and other indicators where glass would be a hazard because of its fragility, has become widespread. If desired, the installation can be made waterproof by taking advantage of the fact that being thermoplastic, the acrylic resin material softens when heated and can be easily formed to shape. When cooled, it will retain this shape until it is reheated when, because of its so-called elastic memory, it will resume its flat sheet form. To make a tight, waterproof joint, therefore, the sheet is heated and formed to the shape of a dome, snapped into position in the mounting ring of the gage, and heated again, upon which the sheet tends to flatten, forming a tight, waterproof joint. Waterproof acrylic resin cements may also be used for this purpose, alone or in combination with gaskets.

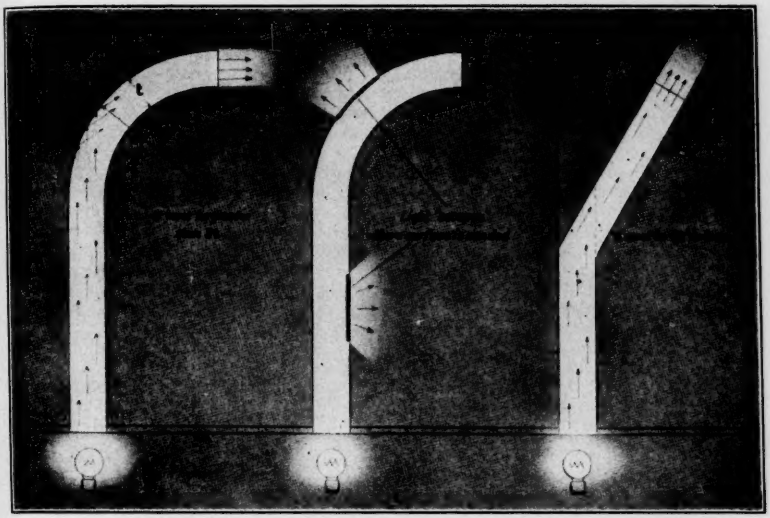
Because acrylic resins are thermoplastic, the sheets can be made readily into curved inspection windows in all types of machinery. After heating in an ordinary oven and then shaping over a wooden form—to fit any strategic part of a machine, the sheet can be mounted securely and simply.

Transparency can also be a big safety advantage. In the G & W Electric Company's subway switch, for example, an acrylic resin sheet permits the operator to make sure the switch is open before working on the switch. Transparency, as well as the need for curved sections also dictated the use of this material in the re-styled Tel Autograph telescriber, the strength of the acrylic sheet reducing breakage both in assembly and in service.

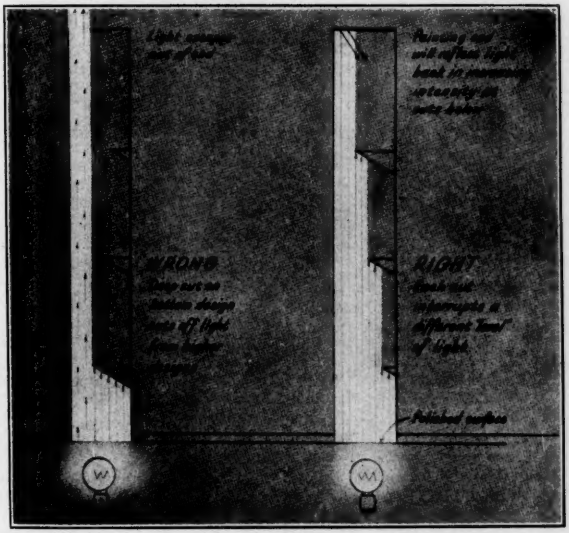
In industrial applications, the acrylics are also useful because of their resistance to most chemicals, to alkalis, to non-oxidizing acids, to oils, to solutions of inorganic salts, and to almost any chemicals except organic solvents and lacquer thinners. Because particles of abrasives bounce from its resilient surface, causing only minor damage, acrylic resin sheets can often outlast glass many times over on grindstone guards and in applications where scratching is a serious factor. If the minor scratches eventually obscure vision through the sheet, they can be polished out on soft linen buffing wheels using fine polishing compounds.

When a large number of any one size and shape of gage glass or inspection window is required, further advantages can be obtained by molding the piece rather than fabricating it from sheet. In the molding operation, particles of granules of the resin are heated and put under pressure until they soften and fuse into moldings identical with the mold in shape. Molding eliminates almost all of the ordinary fabricating operations and can also eliminate costly assembly operations and complicated mounting devices.

Take the case of the General Electric relay cover as an example. Before the advent of acrylics, a glass to cover the face of the relay would have



HERE ARE SHOWN THE LIMITS OF BEND ANGLE AND CURVATURE RADIUS FOR CAST ACRYLIC PARTS THAT ARE TO CONDUCT OR PIPE LIGHT.



INDICATING THE RIGHT AND WRONG WAY OF DESIGNING A MOLDING SO AS TO GET UNIFORM INTENSITY OF LIGHT OVER ALL THE MARKINGS.

been cut to size and mounted in a metal bezel with a rubber gasket which, in turn, would have been screwed to the relay housing. Instead, General Electric molded a cover in one transparent piece. For the sake of appearances, a black rim was painted around the edge of the transparent moldings but there is no other assembly operation. The breakage, of course, both in manufacturing and in service, was materially reduced; and possibly most important, it gave the relay an extra selling advantage.

A large gage manufacturer has ingeniously molded a thread onto his gage cover which enables him to screw his durable, crystal clear molding directly into the housing. It is also possible to mold a flange or rim which can materially simplify mounting without sacrifice of strength.

These simplified mounting arrangements have also been used by leading manufacturers of radios and automomibles to whom assembly costs are vitally important. But they have also used an extra advantage of acrylics—the ability to pipe light from edge to edge with remarkable efficiency. A light bulb placed at the edge of these moldings provides even, glare-free illumination of every marking molded into the piece. In the Philco automobile radio, compact design prevented the installation of the bulb directly at the edge of the dial, but a curved Crystallite molding piped the light around the corner.

The accompanying diagram explains this light piping and also reveals its limitations:

1. Acrylic sheets or moldings will pipe light only around a curve, the radius of which is greater than three times the thickness of the molding.
2. They will pipe light through a sheet bent to an angle of 42 degrees or less.
3. The markings in the molding must be arranged properly if an equal intensity of light is to reach all of them.

Besides these optical limitations, there are several practical ones. The first is that it is difficult to concentrate enough illumination into the edge of any sheet or molding to permit comfortable reading of printed matter under the light transmitted at the other edge. Second, the accompanying diagrams assume an optically perfect surface free of dust and even minor imperfections. While the surfaces of cast acrylic sheets and properly molded Crystalite can closely approximate this perfection, they do fall short of it. And dust we have always with us.

Despite these limitations, a small light bulb with only the simplest kind of reflector provides satisfactory illumination for a dial six to eight inches long, even though that dial may be bent to a fairly sharp angle. Most of the molded dials used on 1941 cars are more than a foot long and are lighted by only two bulbs, one at each end of the dial.

While most of the foregoing discussions have centered on dials molded from powder, most of the considerations also apply to dials, nameplates and other markings stamped into cast acrylic resin sheets. Before stamping or punching the sheet, it is necessary to warm the sheet in hot water or on a steam table. By heating the sheets to higher temperatures and using greater pressures, it is possible to emboss the surfaces with deep designs, rosettes and scrolls to obtain decorative effects. Stamping dies are usually less expensive than molds and stamping is, therefore, used when quantities are small, or when the size of the piece involved is larger than molding facilities available can accommodate.

In the plastics industry, countless improvements in materials, equipment and molding processes are rapidly pushing back frontiers which were hitherto considered sacred. One excellent example of a large molding is a bowl-shaped part for hair driers. It is more than 13 inches in diameter and weighs slightly more than 26 ounces. It is compression molded, and,

included as integral parts are a number of flanges to direct the air current when the drier is in use and to facilitate mounting in assembly. It is a piece which as recently as a year ago might well have been considered impossible.

Within the last year the plastics industry has also come to change its conception of the limitations in injection molding of thick sections. The radiator ornament on the 1941 Pontiac—a piece weighing six ounces and more than a half-inch thick in some sections—was injection molded this year for the first time.

Drug stores have recently been featuring an equally impressive demonstration of heavy sections molded by injection machines. They are Pro-phy-lac-tic brushes molded by Pro-phy-lac-tic after a number of custom molders had refused to undertake the job. These brushes illustrate still another advantage of acrylics based on their crystal clarity. By the

PHYSICAL PROPERTIES OF ACRYLIC RESINS.

(The figures shown in the following table are calculated from standard A.S.T.M. tests on standard pieces at 30 deg. C. and are subject to variation with changes of molding conditions or shapes of pieces.)

POWDER	COMPRESSION	INJECTION
Molding Temperatures	300 to 360 deg. F.	325 to 450 deg. F.
Molding Pressure	2,000–4,000 lb./sq.in.	Medium to high
Compressive Ratio	1.7 to 2.0	2 to 2.4
MOLDED		
Refractive Index	1.49	1.49
Light Transmission	90 to 92 percent	90 to 92 percent
Specific Gravity	1.19	1.18
Specific Volume	23.2 cu.in./lb.	23.5 cu.in./lb.
Tensile Strength	4,000–6,000 lb./sq.in.	
Compressive Strength	10,000–15,000 lb./sq.in.	
Flexural Strength	9,000–12,000 lb./sq.in.	10,000–11,000 lb./sq.in.
Impact Strength (Charpy unnotched bar ½ in. sq.)	1 to 2 ft.lb.	3 to 4 ft.lb.
Mold Shrinkage (Cold mold to cold piece)	0.001 to 0.005 in./in.	0.004 to 0.006 in./in.
Shrinkage after Molding (30 days at 140 deg. F.)	0.001 in.–0.006 in./in.	0.006 to 0.015 in./in.
Thermal Expansion	8×10^{-5}/deg. C. (Approx.)	
Specific Heat	0.4 cal./deg. C./gm.	0.4 cal./deg. C./gm.
Water Absorption by Weight 48 hr.	0.4 to 0.5 percent	0.3 to 0.4 percent
Equilibrium	1.4 to 1.7 percent	1.3 to 1.5 percent
Electrical Properties	Very good	Very good
Burning Rate	Slow	Slow
Machining Properties	Excellent	Excellent
Heat Distortion Point (A.S.T.M. D-48-37)	125 to 165 deg. F.	125 to 140 deg. F.

addition of small amounts of dye, delicate tints may be obtained which add immeasurably to any item where appearance is a selling factor. The permanence of the acrylics' crystal clarity through years of washing and weathering is also an important advantage obtained by the use of this material.

Designers can also look to the aircraft industry which has used cast acrylic sheets longer and more extensively than any other industry. Back in 1936, these were used in windows and occasional flat sections to replace glass or other, less stable, plastics. The light weight, high impact strength,

and permanent transparency were all important. It was not long before further improved methods of installation were developed.

The ease in forming the sheet led to its use in landing light covers and cockpit enclosures or "green houses." Now, observation turrets and machine gun blisters are appearing on America's bombing planes and giving today's pilots the important tactical advantage of all around visibility. More recently, aircraft radio engineers have been using acrylic resins to enclose radio antennae because they found that they did not interfere with radio reception and that these plastic housings permitted the mounting of antennae several feet from the nearest metal part without loss of reception efficiency. Numerous other applications of acrylic resins in the design of aircraft are in process of development.

As is true for every material of construction, best results are obtained only when full consideration is given to all of the production methods to which the material is inherently suited. In the case of acrylic resins these include not only their easy machinability and formability but also the ease with which pieces can be "welded" together.

Not every industry will demand as much of the acrylics as aircraft designers have, but many will benefit from a study of these unusual plastics. They are not miracle materials; they have their limitations; but the acrylics hold out rich rewards to the designer who recognizes all their possibilities for product improvement.

DUSTY CHRONICLE.—Reprinted from the October, 1941, Industrial Bulletin of Arthur D. Little, Incorporated.

In the 1880's British scientists were puzzled by the fact that a hot surface remains clean in a dusty atmosphere, while a cold surface gathers dust. Where pipes at various surface temperatures run through a warm room, or in a building without uniform insulation, pipes, such as cold water conduits, at less than room temperature soon acquire dirt to which warmer pipes seem immune. Grime accumulates on walls and ceilings in streaks and patterns which outline cool areas caused by well-covered girders, laths and even nail heads. Indeed, one advantage of the panel-heating system, in which the room and furniture surfaces are at higher temperatures than the air, is that those surfaces remain freer of dust than if in a room heated by radiators or hot air.

Of recently revived importance to the problems of dust control, this ability of a warm surface to repel suspended particles is explained by the fact that the air molecules are in constant, rapid motion, moving in straight lines and rebounding from obstacles like perfectly elastic billiard balls. The molecules striking a surface warmer than themselves rebound on the average with greater speed and momentum than they had on striking, since they carry with them the energy the surface is losing by conduction. Or, if the surface is cooler than the air, the rebounding molecules are slowed down. Thus, if a current of warm air carries a dust particle close to a cool surface, the particle will be struck by molecules moving more slowly on the side near the surface than on the other side, and it will, in effect, be pushed onto the cool surface. A warm surface, on the other hand, is protected by the hail of accelerated molecules moving away from it and repelling all invading particles which, of course, are huge compared to the air molecules.

About five years ago the British government introduced a dust-sampling instrument utilizing this thermal repulsion which is said to remove from air all dust particles ranging in size from 20 microns down to the smallest

particles visible in the ultramicroscope. (An average human hair is about 30 microns thick.) Tobacco smoke, composed of particles less than half a micron in diameter, is as completely removed as pollen grains perhaps 15 to 25 microns thick.

Ability to handle small particles is important in a dust-sampling instrument or dust filter because by far the greater number of particles in industrial dusts, although only a small fraction of the total weight, are less than two microns in size. These smaller particles tend to be more dangerous, for the larger particles are either filtered out in the nose or caught on surfaces from which they are later expelled, while only the very small particles reach the terminal air sacs in the lungs. Analyses of the lungs of silicotic miners have shown that perhaps three quarters of the particles found were less than one micron in diameter, while only a few per cent were over five microns. In conventionally used instruments of the impingement type (in which the dust-laden air is blown at a high velocity through a small orifice against a test plate), efficiencies are good for fairly large dust particles, but fall off rapidly as the size drops below one or two microns.

Essentially, a dust sampler of the thermal repulsion type consists of a hot wire centrally mounted between two closely adjacent cool surfaces, against which the dust particles are pushed as they are repelled by the hot wire. With its auxiliaries, the instrument may be carried by one man, but it is considerably less compact and requires more time per reading than some instruments of the impingement type, the minimum time for a reading being about ten minutes. On the other hand, its ability to precipitate dust continuously as air slowly flows through it makes it an ideal instrument for obtaining so-called occupational dust records which show the average concentration to which a man is exposed over a period of time. A miner may spend most of his time in relatively clean air, and a reading taken while blowing out a drill hole would give an exaggerated view of his danger. The "thermal precipitator" has been used in the Witwatersrand of South Africa to follow a miner during an entire shift and thus record a measure of his average dust exposure, information otherwise difficult to obtain.

Although the use of thermal repulsion is now restricted to analysis, a recent discovery that a heated screen or lattice will act like a solid surface in repelling dust points toward the use of this principle for dust filtering. The screen may be considered as a membrane that lets air molecules pass, but repels the larger, slower-moving dust particles. Particles are not caught on the screen, but are prevented from touching it, indicating that such a filter might be non-clogging. Laboratory results indicate that such a filter would be of extremely low resistance to the passage of air, yet have a filtering efficiency of over 90 per cent.

ICELESS ICE.—This item first appeared in Compressed Air Magazine. It is here reprinted from Current Topics in the November, 1941, issue of the Journal of the Franklin Institute.

Most of us have heard of dry ice and have probably carried home a carton of ice cream packed in this solidified carbon dioxide to keep it frozen. But hot ice, so called because it reaches a temperature of as much as 78 degrees F. is another matter. It is not a refrigerant, but otherwise has the characteristics of real ice and is being used in place of it in indoor skating rinks. Mark ice, as it is named after its inventor, John Markman,

is a mineral product that is applied in liquid form. It sets almost immediately after spraying, it is claimed, making it popular with hotels where ice-skating revues are a feature of the entertainment. With the program finished, the floor can be quickly resurfaced, if necessary, for dancing. There is a rink of this kind in the Persian Room of the Sir Francis Drake Hotel in San Francisco, Calif. It measures 19 x 30 feet and has a ¾ inch coat weighing 3½ tons, or approximately 2½ tons more than genuine ice of the same dimensions and thickness would weigh.

BLACKOUTS.—Major Charles W. Stewart, Jr., discusses a subject about which we are all fast becoming informed. His article, copied from the May-June, 1941, issue of the Military Engineers, includes considerable information not yet published in the daily press.

The term "Blackout" is apparently due for an increasing amount of publicity and actual application in the life of the average American during the coming months. No newspaper reader can fail to know that a blackout means the reduction or extinction of all forms of night lighting and glare that might assist an enemy bomber to locate and identify his target. To assist in blackout preparations all engineers, whether military or civil, are going to be expected to be informed and helpful along whatever lines they are best fitted. However, except for the few who have been making a special study of some phase of the subject, most will find that their ideas are rather hazy. Up to the time London was bombed, the idea of civilian participation in blackouts and similar forms of preparedness for war had been repugnant to the majority of the people of the United States. Only a few blackout exercises (such as those in New England, North Carolina, Panama, Honolulu, and Seattle) have been held, usually in connection with military air maneuvers or air raid warning system tests. General nationwide education on the subject has been lacking; however, the growing awareness of the public to the dangers of air attack may soon make such exercises more common.

Most of the available information is necessarily from foreign sources; the bulk is from British ARP publications. However, the problem in England and Europe, in general, is more immediate and considerably different from the problem in the United States. Very little has been published about blackouts in the United States. In the near future, however, a number of pamphlets may be prepared by the War Department and other governmental or civilian agencies on various phases of civil defense. These would be designed to provide information and guidance for the purely civilian organizations which probably would be charged with the protection of the civil populations and industrial centers and which would have only such general guidance by military commanders of the larger geographical areas as may be essential. Except in areas more or less under military and naval control, civilian agencies would have full responsibility.

Blackout is merely one phase of civil defense procedures, but a most important one, because it would possibly be the first step should hostilities become imminent, before air raid shelters, gas, fire, and other protective measures might be required. Within an area of several hundred miles from our borders or coasts (depending on the possible direction of enemy attack) all forms of lighting in nearly all cities, towns, villages and houses and on roads, railroads, streams, and airways will have to be controlled so that they may be extinguished or dimmed on short notice. Localities on or near such coasts or the battlefront would have to be blacked out habitually should war begin.

No blackout, however perfect, can on cloudless or moonlit nights conceal the presence of great cities and industrial areas, especially when they are located on or near rivers, seacoasts, lakes, or other similar large natural geographical features. Flares dropped by the enemy, fires started by incendiaries on the ground, and excessive use of poorly placed antiaircraft searchlights will tend to nullify the effectiveness of the blackout. Nevertheless, a blackout helps to prevent identification of the locality as a guide post to more distant vital areas, conceals the location of specific targets in the area, and avoids haphazard bombardment of still lighted unimportant areas through failure of an enemy to find his other assigned objectives. The kinds of light to be blacked out are: primary sources emitting light such as street lights, and signs, as well as factory or furnace glows, city dumps and fires started by incendiary bombs or sabotage; reflections of light as from metal roofs, large glass window areas, light colored buildings, roadways, and bodies of water. As street and other lights form characteristic patterns, variations in and additions to such patterns as a means of deceiving or confusing the enemy are being studied in the event that completely effective blackouts are not feasible in certain areas.

Air Raid Warning Service.

An essential element of blackouts is the Air Raid Warning Service (ARWS) which is a combined military-civil organization set up for the purpose of locating approaching air attacks long before they reach their probable targets, reporting this information continuously to central focii for collection and analysis, and the dispatch of warning to civil areas likely to be attacked or passed over in the attack of important areas beyond. The organization of such an information system is chiefly the responsibility of the United States Army Signal Corps and various telephone, telegraph, and radio agencies, since the matter is essentially one of communications. A more complete description of the ARWS is beyond the scope of this article. Another type of civil defense also involved in blackouts is camouflage both by day and night; in fact during the hours of darkness, the blackout and other measures of light control will be the chief method of camouflage employed in most cases, and all possible means of daylight camouflage will be utilized to contribute to the success of such light control or blackout measures at night. In planning for protection of existing and new installations, blackout and camouflage requirements must be co-ordinated and considered together. Concealment by both night and day should be one of the fundamental considerations of location and design of all new construction for defense production.

Organization and Training.

The organization to control blackouts will vary with each community, but in all cases it will be a local civil responsibility supervised by the military only in its larger aspects and advised and assisted by them in every possible way. Something similar to the British air raid warden system will probably be instituted, making one trained person responsible for each house, apartment house floor, city block, and so on. Each group of wardens should be responsible to and trained by the next superior in the organization. The whole may be supervised by or work in co-ordination with existing police and other municipal service organizations. The time, money, and effort spent in selecting, equipping, and training such personnel will be well repaid when their services are needed.

To be effective, this system together with fire control, first aid, and rescue work will require co-ordinated individual training, drills, tests, and practice

exercises and trained instructors and leaders. Successful operation under the most severe blackout restrictions will be the required standard of performance before individuals and units are considered adequately trained for their tasks. All available publicity facilities of the community should be enlisted to secure the wholehearted co-operation of the public regardless of class, trade, age, or ability. Surveys should be made of all installations and facilities involved in blackouts by enlisting the services of all civic, social, and trade organizations. Progressive tests in smaller groups should be followed by actual exercises with larger ones on which checks and reports are made to correct errors. Photographs and observation from both ground and airplanes are of value for this purpose. Although such tests usually last for only 15 to 60 minutes, all areas should be able to put on a prompt and full-time blackout if necessary as soon as hostilities become imminent. To insure compliance and set forth fully the measures which are necessary and authorized, some form of legal authorization for blackouts will have to be enacted in each civil community by the state, county, city or other law-making body. As in England, some form of grant in the form of money, labor, or materials may even be provided for in such enactments which may also cover all other forms of civil defense measures. Such assistance will assure uniform compliance with requirements.

Three important fundamentals which should be considered in setting up such an organization are to:

1. Elicit complete and enthusiastic co-operation voluntarily from the public by extensive and intelligent publicity.
2. Produce a maximum in efficient results with the minimum disruption of normal procedures and organizations and using no more transport, personnel, and supplies than are essential.
3. Require observance of only such blackout measures as are effective and requisite. Obviously excessive restrictions will be violated or ignored.

Enforce such regulations as are prescribed without laxity or exceptions of any kind unless in the interest of the public as a whole. Many blackout provisions will work a hardship on all those involved in extra costs, trouble, inconvenience, and labor. Hence, restrictions should be reduced to the inescapable minimum and then carried out without fear or favor by an impartial authority having full power and means to do so, with public moral support to back up any action taken.

Blackouts in areas fully controlled by military and naval authorities should employ the same measures and utilize the existing service organizations to accomplish the same purposes as those required in civilian communities. Complete co-ordination between adjacent civilian and military or naval areas will be of primary importance to both. In all cases, geographical and industrial boundaries should determine what localities should be included in any given blackout area rather than political boundaries which might well be a source of friction and disastrous misunderstandings. Any area that should be under one single authority for blackouts should not be split among many, or, if so divided originally, a working master organization (on the lines of the Port of New York authority) should be instituted as soon as possible.

Methods of Lighting Control.

The many means and methods used for control of lights in blackouts may be grouped as follows:

1. Control of the light source itself by extinguishing or dimming measures.
2. Shielding or masking any outlets through which the full intensity of interior lighting might escape.

3. Installation of reflectors to pick up light or use of luminescent and indirect lighting means to serve as warnings and guides.

The prompt extinction of fires caused by incendiaries and the shooting down of parachute flares are also important in this connection but do not properly warrant discussion in the limited space available. Nevertheless, lack of such measures can partially nullify the effectiveness of an otherwise satisfactory blackout and, therefore, they should always be covered in all blackout planning.

One of the simplest methods of blackout might appear to be to cut off all power at a central switch. In actual practice this usually is impossible except in very small towns, as power is needed for subways, elevators, pumps, refrigeration and ventilation systems, operating rooms, inside illumination, and emergency lighting. In fact, if power does go off, alternative sources must be available as standbys to keep all necessary equipment in operation. Moreover, the purposes of the blackout would not always be served by the total extinction of all lights of whatever nature. Such a procedure would be quite unnecessary in many cases (although requisite in a few), and would result in a paralysis of all outdoor and many indoor operations which have to be carried on in wartime. Requirements for lighting which may be authorized during blackouts in general are:

1. To be invisible as a means of giving ground location identifications to an enemy bomber or pilot flying at a minimum speed and altitude; both will vary between wide limits but may be taken usually as about 200 M.P.H. and 1500 feet, respectively. At normal speeds a point target must be surely and quickly located several miles away at a low oblique angle or it will be missed entirely by the bombing attack.

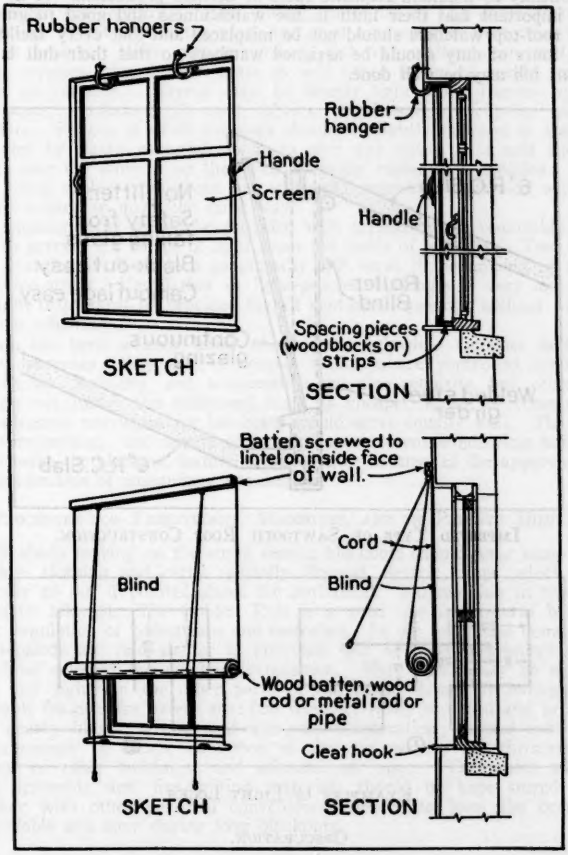
2. To be visible to pedestrians and drivers on the ground at a distance of about 300 feet when moving at slow speeds (3-15 M.P.H.). These two requirements are not incompatible as there is a relatively narrow range of low light intensity that will satisfy both. This range will vary depending on many factors and types of lights. For street lighting (with guide lamps 100-150 yards apart) the pedestrian needs about .0004-foot candles whereas intensities in excess of .001-foot candles may be noted from the air. For blackouts low intensity light within these limits must be quite uniform in any small area lest sharp contrasts blind the pedestrian or be noted from the air.

Procedures in Event of Attack.

In actually putting a blackout into effect, the ARWS should inform the local civil defense headquarters in the area that an attack is impending. A system of local communications is called into play involving telephones, radios, automobiles, and all other types of messenger service to warn all civil defense agencies to stand by for probable action. Advance telephone warnings are transmitted by code words (changed frequently) so that the public will not be unnecessarily alarmed. When attack is imminent the public is warned by sight or sound signals or combinations of both. Outdoors all types of sirens, bells, whistles, horns, and blinking lights may be used. Indoors bells, buzzers, telephone rings, radios, loudspeaker systems, or surge in light voltage or blinking lights on telephone or special circuits may be used. Such warning signals should be uniform over the entire country in order to avoid confusion.

Street and other forms of municipal lighting are rapidly controlled from central points and substations. Interior lighting and outside signs are handled by individual owners except that all circuits that might be overlooked should have an easily accessible switch that can be quickly reached in an emergency by the local warden. Dimming or extinction of all outside lights

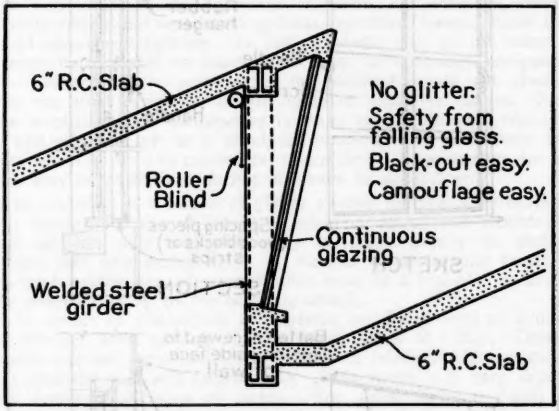
except those authorized with low intensity should be accomplished within about five minutes. Bombers approaching at 300 M.P.H., unless reported far off the New Jersey coast, could easily be within sight of the lights of Philadelphia within that time.



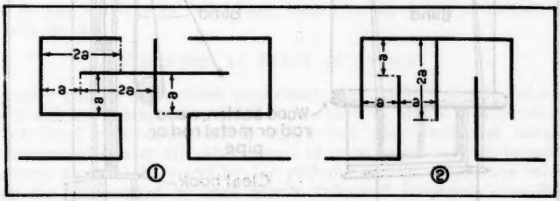
TYPES OF EFFECTIVE WINDOW SCREENS.

The decision as to whether to continue to work or to cut off lights and power for machines and send men to air raid shelters is a vital one in defense industries. If this should be done whenever a single plane attacked, a great slowing down in production could be caused with relatively little effort or cost on the part of the attacking enemy. Hence, roof-top watchers, repre-

senting both owners and workers, with warning equipment should be posted to determine when warnings should be given for the best interests of the nation and safety of the workers. As long as employees know that all possible steps to provide for their safety are being taken they will co-operate patriotically to maintain requisite rates of defense production. It is, therefore, important that their faith in the watchfulness and good judgment of their roof-top watchers should not be misplaced and that every facility and short tours of duty should be assigned watchers so that their dull but important job may be well done.



IMPROVED TYPE OF SAWTOOTH ROOF CONSTRUCTION.



EXAMPLES OF LIGHT LOCKS.

OBSCURATION.

The darkening of plants which are kept lighted inside is called obscuration. One of the simplest of these methods is the painting of the glass with weatherproof compounds or paints. However, under bombings or even falling antiaircraft shell fragments, if the glass is broken, this would be ineffective. Wherever possible, wired glass or transparent plastics should be used in place of ordinary glass panes for new construction or replacements. Almost all glass of any kind within 200 feet on a direct line from an exploding HE bomb may be broken by the direct blast effect.

Adhesives applied to glass will add some strength, cut off light and (if outside) prevent reflections. Some of these materials are papers, fabrics, plastic films, rubber latex, and bituminous materials. Outside obscuring shades and shutters protect the glass, prevent reflections from them and may serve to aid in daytime camouflage, but they must be able to stand exposure to the weather. Inside sliding, roller blinds and other forms of obscuration do not protect the glass and must give weather protection if the glass is broken. Wire netting with ½-inch or smaller mesh will stop serious injuries from broken glass as will other forms of inside screens, shades, or curtains. Screens may be merely light wood frames covered with paper, cardboard, plywood fabrics, metal sheets, or other similar materials. Screens in small windows should be lightly fastened in and also suspended by elastic materials so as to give way easily as a unit and yet remain near the window so they can be easily replaced in position. Roof lights being visible from above are still more important than side windows but are treated in much the same way.

All outdoor exits should be provided with permanent or removable light locks to prevent the escape of light from the inside of buildings. Two light-proof curtains or doors in a passageway will serve if the amount of traffic is not too great. Ventilation in light-proofed buildings is very important and light traps must be provided for all ventilator openings without impairing their efficiency.

Much has been written lately about the windowless factories built for defense purposes; they are, of course, useful where controlled conditions of light, air, humidity, and temperature are also requisite, but, otherwise, they do not justify the additional costs as cheaper forms of construction with adequate provisions for blackouts would serve equally well. The location, surroundings, and structural form of some recent windowless buildings would make the blackout feature of little value because of the apparent lack of consideration of camouflage possibilities.

Procedure for Pedestrians, Motorists, and in Private Homes.

Individuals moving on the street during blackouts should wear some items of white clothing and carry specially dimmed electric lamps which automatically go out if pointed above the horizontal. No smoking in the open should be allowed. The Golden Rule is a good one for general blackout traffic regulation of pedestrians and motorists. In the individual home, even if a separate air raid shelter is provided, one or more convenient rooms should be selected for blackout occupation. Here lights may be used as usual, but lights in the other parts of the house should be extinguished. Desirable features for safety are: few windows easily screened and protected from nearby blasts; strong roof and wall construction; several exits; elevation enough to escape collection of gas and water; not threatened by collapse of other buildings; and adequate air space. Equipment such as extra screening and fire-fighting materials should be kept stored there, together with other personal conveniences needed to keep the occupants comfortable and busy during long blackouts.

Tests and Research.

One of the most important things to be done to make blackouts effective is to have a control test and research organization to carry out the functions of the British Home Office which prepared the Air Raid Precautions handbooks, specifications, and other material issued in England beginning two years before warfare started. The Council of National Defense is preparing to issue certain pamphlets but many technical tests need to be

made by the best experts available on matters involved in blackouts such as: traffic control and motor vehicle lighting; railroad, ship, and air transport traffic lighting; uniform specifications for all types of blackout materials found to be most effective after tests for use in various parts of the country; special methods for control of glare or glows from industrial plants, such as steel mills, gas plants, oil refineries, et cetera.

Effectiveness.

Many persons may not be convinced that backouts are of any use in reducing the effectiveness of air bombings. It is true that blackouts can be nullified to some extent by dropped flares; that blackouts add to the fear and moral effect of night raids, handicap various civil defense efforts, and force firefighters to work in accentuated bombing target areas; that they destroy social life, endanger civil morale, hinder transportation and shipping, and (even when no bombings occur) are responsible for many casualties on streets and highways. Indeed, one English writer even goes so far as to advocate complete abandonment of blackouts and instead blinding the enemy with a blaze of illumination from a vast network of lights around geographical landmarks and objectives. This system might conceivably have a limited application in England and in some parts of the United States, but for the greater portion of this country the chief passive defense against air attack (at least initially at the start of hostilities) would probably be some form of blackout. No airways passenger who has passed over our towns and cities at night in peace would want them to be so viewed by enemy bombers (or even with a thousand times that much illumination) especially where indiscriminate bombing of civilians was being carried out. Future American blackouts may be different from continental ones in details, technique, and even in name but, in essence, they will be blackouts just the same.

WOODEN CAISSONS.—This abstract of U. M. Begak's article, which appeared in Sondostroienie, March, 1941, is copied from the November, 1941, Transactions of the Institute of Marine Engineers. It describes how caissons may be used to permit major repairs afloat in areas where drydock facilities are not available.

In the spring of 1940 it was found that the Arctic icebreakers *Lenin* and *Litke* had developed a number of serious defects in their propellers and rudders, in addition to which certain portions of the underwater stern plating of both vessels required renewal. The extent of the repair work involved was beyond the capacity of divers and would in ordinary circumstances have involved placing the ships in dry dock, but as no docking facilities were available it was decided to carry out the work with the aid of watertight caissons built at Archangel. In the case of the *Lenin*, the caisson was a trough-shaped structure, constructed of stout timber, closed at one end and fitted with a portable wooden shield at the other. The cross section of the caisson corresponded to the shape of the stern of the icebreaker. The latter was trimmed down by the bow in order to raise the stern as much as possible, and the caisson was then hauled into position and weighed down by means of ballast in the form of a quantity of chain cable lowered into it by means of a floating crane. When the caisson was secured in place under the stem of the ship, the portable wood shield was lifted out by the crane and sufficient water permitted to enter to immerse the caisson to the correct depth, which gave it a maximum freeboard of just over 19 inches. The water was then pumped out of the caisson, during which

operation it was kept hauled up to the hull plating of the ship at its open end by means of blocks and tackles, and the necessary shores inserted between the hull and the bottom and sides of the caisson. By this means the propellers and rudder of the ship were raised clear of the water and made accessible for repairs. No difficulty was experienced in keeping the caisson clear of water during the six weeks it remained in position for the completion of the repair work, after which it was once more flooded and hauled clear of the ship. The overall length of the caisson used for the *Lenin* was about 56 feet, the width at the top of the sides about 61 feet reduced to about 40 feet at the bottom, the height of the sides just over 26 feet, and the draught while in use and pumped out about 20 feet 6 inches. The total weight of the structure was 184 tons and it had a lifting capacity of 800 tons. The caisson used for the *Litke* was similar in design, but of somewhat different dimensions. Both caissons were built simultaneously within a period of 28 days and were launched with the aid of wooden rollers, as no slips were available. The experience gained in this instance indicates that the employment of caissons of similar type should make it possible to carry out large underwater repairs to the hull of a ship in many cases which would ordinarily involve the use of a dry dock.

CORROSION OF STEEL BY STEAM AT HIGH TEMPERATURE.—The following abstract of a paper presented at the Fall Meeting of the American Society of Mechanical Engineers by H. L. Solberg, G. A. Hawkins, and A. A. Potter is copied from the October, 1941, issue of Combustion. The gradual approach of steam temperatures to those used for the commercial production of hydrogen by the reaction between steam and iron prompted this paper which presents some of the high spots of an investigation undertaken by Purdue University of the corrosion by steam of the various steels available for high-temperature steam service.

A previous progress report[1] presented by the authors before the A.S.M.E. in 1937 showed the effect of temperatures from 800 to 1200 F. on the oxidation of low-carbon steel in contact with steam at 1200 pounds per square inch in which it was found that the rate of oxidation of low-carbon steel at 1100 F. is independent of pressure between 400 and 1200 pounds, the range explored.

The present report deals with a continuation of the investigation with unstressed specimens of a wide variety of steels and alloys having for its object the effect of various types of surface finish and methods of scale removal; the effect of time of exposure to steam at 1100 F. for various intervals of time up to 2000 hours; the effect of exposure for 500 hours at steady stem temperatures from 1000 F. to 1300 F.; the effect of temperature fluctuations on the corrosion resistance and spalling of scale on round bars as well as convex, concave and flat surfaces; and the corrosion of cast steels and special alloys.

Methods Used for Measuring Corrosion Products.

Steam reacts with steel according to the equation

$$4H_2O + 3Fe = Fe_3O_4 + 4H_2$$

While this reaction indicates that the amount of corrosion could be measured from the quantity of hydrogen evolved, the occluded gases in the steel

[1] Potter, A. A., Solberg, H. L., and Hawkins, G. A., "Investigations of the Oxidation of Metals by High-Temperature Steam," Transactions, A.S.M.E., 59, 725 (1937).

and the permeability of steel to hydrogen introduced variables which made the method unsuited for this investigation.

An attempt was made to measure the extent of corrosion by stripping the scale from corroded specimens by the use of hydrochloric acid, antimony trioxide and stannous chloride, but this solution failed to remove the scale from steels high in chromium, although it was satisfactory for low-carbon steel.

A series of experiments with other acid and inhibitor combinations was then undertaken and it was found that a 34 per cent sulphuric acid solution with 0.1 per cent quinoline ethiodide would remove the scale from low-alloy steels with no appreciable attack on the base metal. However, no combinations of acids or concentrations of quinoline ethiodide would remove the scale from steels containing 12 per cent chromium or more without pitting the metal.

Scale removal by electrolysis was also tried, but the method finally adopted consisted of weighing the clean specimen before exposure to steam, removing the scale by electrolytic stripping after exposure to high-temperature steam, and reweighing the specimen. The solution consisted of 10 per cent sulphuric acid with one gram per liter of quinoline ethiodide, the specimen serving as the cathode. The time required for stripping with a current density of one ampere per square inch varied with the chromium content.

All the specimens were annealed, the cast steels being received in an annealed condition.

Figure 1 shows the effect of time on extent of corrosion with steel tubes of different compositions in contact with steam at 1100 F. for 100, 200, 500 and 1000 hours and Figure 2 the results with a number of different alloy bars in contact with steam at 1100 F. for 200, 500, 1000 and 2000 hours. In all cases the corrosion rate was most rapid during the first 100 hours after

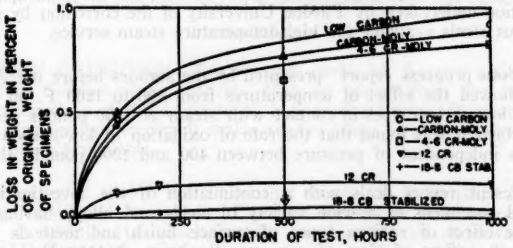


FIGURE 1.—CORROSION OF STEEL TUBES IN CONTACT WITH STEAM AT 1100 F. FOR 100, 200, 500 AND 1000 HOURS.

which the layer of corrosion products retarded the rate of oxidation. In general, the corrosion was found to decrease as the chromium content of the steel increased and high-chromium steels were practically corrosion-resistant.

Figure 3 represents the relative corrosion results with cast steels in contact with steam at 1200 F. for 570 hours. In general, the corrosion of cast-steel specimens was not materially different in amount from that of the rolled steel specimens.

Further tests with the special alloys, Stellite, Hastelloy, Colmonoy and Lamite, showed all to be extremely resistant to steam corrosion.

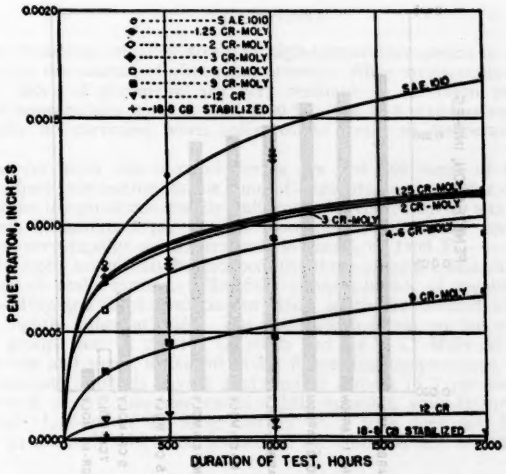


FIGURE 2.—CORROSION OF STEEL BARS IN CONTACT WITH STEAM AT 1100 F. FOR 200, 500, 1000 AND 2000 HOURS.

EFFECT OF TEMPERATURE CHANGES.

Specimens of five different unstressed steels were placed in contact with superheated steam at a steady temperature of 1200 F. for 500 hours. At the end of this period three specimens of each steel were removed and stripped electrolytically in order to measure the loss in weight due to corrosion. One-half of the remaining specimens were held at 1200 F. with sudden cooling to room temperature in nitrogen and heating again to 1200 F. every 100 hours until the total time in contact with 1200 F. steam was 1200 hours. The remainder of the specimens were treated similarly except for a 50-hour cooling cycle. Specimens were removed after 700 hours and also at the end of the test, in order to measure the extent of the corrosion.

The first visible evidence of extensive cracking of the scale occurred after a total exposure to steam of 700 hours. The result of visual observation during the test indicated that the layer of corrosion products is thinner and more brittle as the chromium content increases up to 5 per cent. An examination of the specimens indicated that the scale on the low-carbon-steel specimens was very thick, porous and, in spite of the severe temperature shocks, spalled only slightly as compared to the 4-6 Cr steel. The 2 per cent Cr steel spalled less than the 3 per cent Cr steel while the third layer of scale was cracking in the 4-6 per cent Cr steel at the end of 1200 hours. Little scale formed on the 9 per cent Cr steel and a microscopic examination of the surfaces at the end of the test failed to show evidence that the scale had cracked or checked.

Figure 4 shows the influence of chromium content on corrosion of steels during intermittent operation at 1200 F. for 1300 hours.

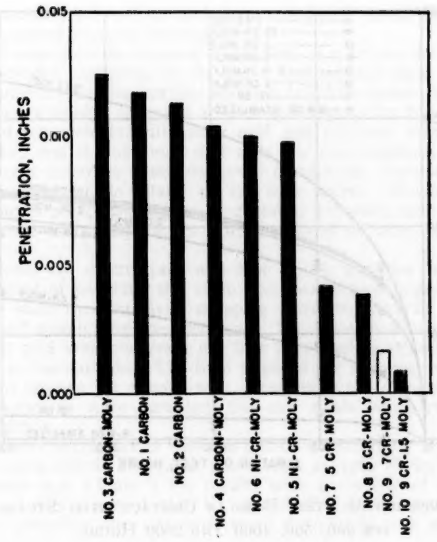


FIGURE 3.—CORROSION OF CAST STEELS IN CONTACT WITH STEAM AT 1200 F. FOR 570 HOURS.

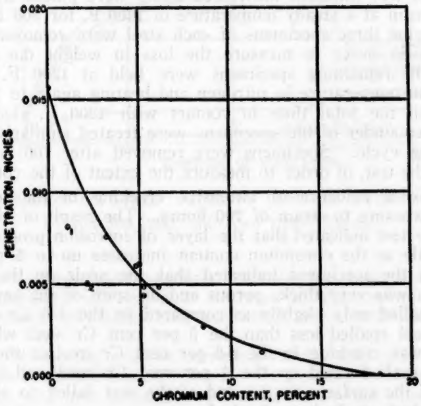


FIGURE 4.—INFLUENCE OF CHROMIUM CONTENT ON CORROSION DURING INTERMITTENT OPERATION.

Conclusions.

1. The resistance of alloy steels to high-temperature steam is greatly influenced by the amount of chromium present. Alloy steels containing 7 per cent or more of chromium are very resistant to corrosion produced by steam at temperatures up to at least 1400 F. The 18-8 stainless steels showed practically no corrosion when subjected to steam at temperatures up to 1400 F.
2. The corrosion rate is rapid during the first 500 hours of testing and then gradually diminishes as the time of exposure to the steam continues.
3. Steam temperatures greatly influence the corrosion of steels. Except for steels containing 7 per cent or more of chromium, the corrosion rate increases very rapidly at temperatures in excess of 1100 F.
4. The steels tested may be grouped into three general classes according to the type of scale formed. The first group consists of low-carbon steel, Carbon-Moly and the low-chromium steels which are covered with a thick, porous, tightly adhering scale. The scale which forms on the steels of the second group, that is, the 4-6 Cr steels and the 2 Cr-Moly-Al-Si steel, is very brittle and easily flakes off under fluctuating temperatures. The third group consists of steels having a chromium content of 7 per cent or more upon which a very thin non-porous tightly adhering scale is formed.
5. Scale formed on the inner surface of a tube does not flake off as readily as the scale which has formed on the outer surface of a tube.

ELECTRICAL MACHINE SOLVES HEAT-TRANSFER PROBLEMS.—In 1938, following 16 years in various European countries, Victor Paschkis found opportunity to escape an intolerable situation and made his way to America. Originally connected with the Vienna Institute of Technology and possessed of a specialized knowledge of heat transfer, he soon found a university research connection with Columbia University. Dr. Paschkis convinced a special investigating committee of the soundness of his proposal to construct a radically improved form of the heat-transfer electrical "model" first developed by C. L. Beuken, a Dutch scientist with whom he had worked just before coming to America. Following the favorable report of the committee, Dr. Paschkis was given the use of a laboratory and sufficient funds to finance his equipment. This article, reprinted from Power, July, 1941, reports the equipment accurate, practical, and ready to solve difficult heat-transfer problems submitted by industry.

Newspaper men call it an "electrical brain"—a popular name for almost any piece of electrical equipment used to determine almost anything. Whatever you call it, a remarkable electrical device, recently assembled at Columbia University, New York, does the work of a mighty good human brain in the solution of heat-transfer problems—in fact solves problems far too difficult or tedious for our best-heeled experts in applied mathematics.

The man principally responsible for this installation—Dr. Victor Paschkis—was a research engineer in various European countries before he came to America in 1938. Working with H. D. Baker, instructor in Mechanical Engineering at Columbia, and using funds advanced by the Research Foundation (Washington, D. C.), Dr. Paschkis has practically covered three walls of his laboratory in the engineering building with stacks of trays of electrical condensers and resistances, with elaborate plug boards for cross connections. To the casual observer it looks like a cross between a telephone exchange and a radio shop.

In somewhat technical language Messrs. Paschkis and Baker told the

story of this equipment in Philadelphia on June 20, at the national meeting of the Applied Mechanics section of the A.S.M.E. Back of their differential equations was a romantic story—and one of broad engineering interest.

This remarkable device is destined to play an important part in American engineering research—to cut into the big area of guesswork in the solution of heat-transfer problems, replacing today's guesses by measured facts. That is why engineers everywhere should know what it is, how it works and what it can accomplish.

Fundamentally, what Dr. Paschkis does is to plug in electrical quantities analagous to the thermal quantities to be investigated. He then "turns on the juice" for a specified time and measures what happens in electrical terms. These can be translated directly into the desired terms of heat transfer—thus giving the answer to the original problem electrically "set up" on the machine.

Dr. Paschkis gives full credit for the original idea of solving transient heat-transfer problems by an electrical model to C. L. Beuken, Dutch engineer, but he has notably improved Beuken's original apparatus.

Electrical Parallel.

Engineers have long noted a close parallel between steady heat flow and steady electrical flow. As a simple case, consider a metal rod insulated so heat can flow from one end to the other, but not out the sides. Keep one end at constant high temperature until a steady condition is attained. Heat will flow from the hot end of the rod to the cold end at a rate directly proportional to the difference in temperature between the two ends and inversely proportional to the heat resistance of the rod. The heat-flow equation is:

Btu. per hour = Temperature difference ÷ Resistance to heat flow.

In this formula the unit of heat resistance would have to be that resistance which would permit one Btu. per hour to flow with a temperature difference of one degree F.

Now for the electrical parallel—again a metal rod or wire of appreciable resistance. Apply a steady voltage across its ends and a current will flow directly proportional to the voltage and inversely proportional to the electrical resistance. The formula here is the well known Ohms Law:

Amperes = Volts ÷ Ohms.

Since this has exactly the same form as the formula for steady heat flow, it follows that you could solve any simple heat-transfer problem of this type by setting up Ohms resistance equal to the heat resistance, applying volts equal to the temperature difference. The resulting amperes of current will be numerically equal to the heat flow in Btu. per hour. Such a problem could be electrically solved in this manner, but nothing would be gained, for it would be much easier to get the answer by simple arithmetic.

The task Dr. Paschkis set himself started with this simple concept, but developed into something far more elaborate, complete enough to match difficult practical heat-transfer problems in which the heat flow is in three dimensions, and changing from moment to moment, and in which the body is of irregular shape and composition.

With extreme ingenuity Dr. Paschkis has met these many requirements. You can send him a scale drawing of a mass of fish interspersed with refrigerating pipes. Give him the data on pipe temperatures, heat conductivity and specific heat of the fish. He will plug this data in on his switchboards, throw on a direct current of specified voltage for a specified num-

ber of seconds, read certain voltmeters and then tell you what would be the temperature of a fish at such and such a point in the mass, so many seconds after the cold was turned on.

Exactly the same technique can solve a problem of cooling molten steel in an ingot mold, heating up a backing layer of brick in a furnace wall, or the rapid-fire ebb and flow of temperatures in a diesel-engine piston head.

When heat flow is unsteady the equipment must provide for heat storage as well as heat resistance. The wave of heat set up in a cold rod by the sudden warming of one end is slowed down if the heat capacity of the rod is high. You might say that the heat has to take time out to fill up all the voids in the rod before it can reach that steady state where as much heat comes out of the cold end of the rod as enters the hot end.

This storage business is easily handled by adding electrical capacity to the circuits at the right points. Consider a simple case of straight-line heat flow in an insulated metal rod (Figure 1). Imagine the rod arbitrarily divided into sections as shown. You know the heat resistance and the heat

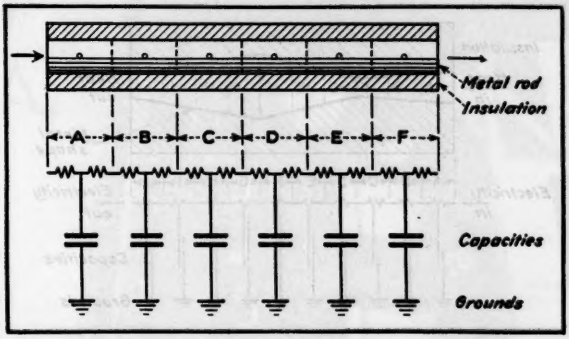


FIGURE 1.—ELECTRICAL SETUP FOR ONE-DIMENSIONAL HEAT FLOW IN THE UNSTEADY STATE. TEMPERATURE DIFFERENCE BECOMES VOLTAGE DIFFERENCE. HEAT RESISTANCE BECOMES ELECTRICAL RESISTANCE. HEAT CAPACITY BECOMES ELECTRICAL CAPACITY. BTU.'S BECOME COULOMBS OF ELECTRICAL CHARGE. BTU.'S PER HOUR BECOME AMPERES.

capacity of each section, and can set these up on the machine as the corresponding electrical resistance and electrical capacity. The capacity, concentrated at the middle of each resistance, is obtained by plugging in a condenser of proper size.

PLUGGING IN RESISTANCES.

For each section of the rod, plug in electrical resistance in ohms equal to the heat resistance of the section measured in the unit already described (unit resistance is that which allows one Btu. per hour to flow with a temperature difference of one degree F. across the section). Set up the electrical condenser capacity in farads equal to the heat capacity of the section in Btu. per degree.

When all these resistance and capacities are connected in proper order as shown, apply to the two ends of the network a direct-current potential difference equal to the temperature difference between the ends of the rod. Apply the voltage for a time in *seconds* equal to the time in hours for which the heat flow is to be investigated. The charge transmitted in ampere seconds will equal the Btu. flowing into the hot end of the rod, or out of the cold end. The instantaneous voltage read at any point in the circuit will determine the temperature at that point in the rod.

Figure 2 is one step more difficult. Here the insulated rod has an irregular cross section. That means that each section has a different resistance and a different heat capacity. For equal lengths the thin sections will be high in heat resistance and low in heat capacity, and the thick sections the reverse. These are set up electrically as shown, with corresponding variations in electrical resistance and electrical capacity. These variations are roughly indicated in the sketch. (Large condenser capacity is represented

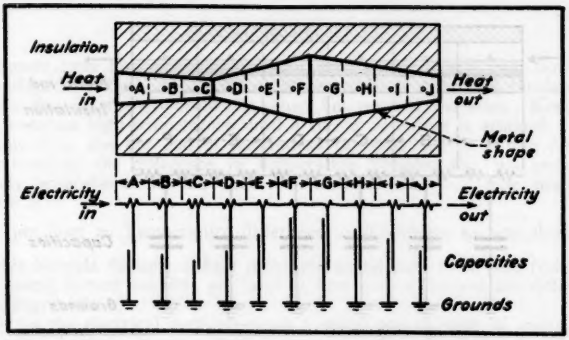
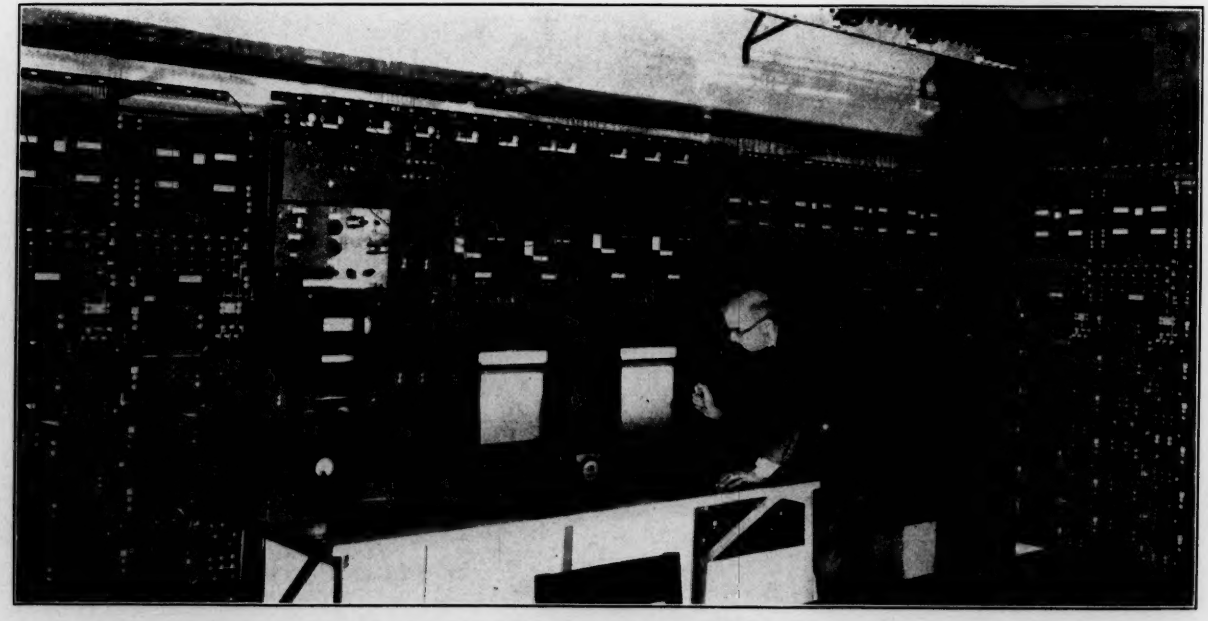


FIGURE 2.—LIKE FIGURE 1, EXCEPT THAT THE METAL HEAT PATH IS OF IRREGULAR SECTION, SO THAT RESISTANCES AND CAPACITIES VARY FROM ONE SECTION TO THE NEXT. AFTER THE SETUP IS ONCE MADE THIS PROBLEM IS SOLVED AS QUICKLY AS THAT OF FIGURE 1 BY PLUGGING IN DESIRED DC VOLTAGE FOR PROPER TIME AND READING INSTRUMENTS.

by large overlap of condenser plates.) Once set up on the switchboard, the problem is solved (as in Figure 1) by applying the proper DC voltage for the predetermined time. Electricity trickles along the rod, pausing to "fill up" the various condensers. Ammeters measure "heat flow." Ampere-hour meters measure Btu. Voltmeters measure temperatures.

Figure 3 illustrates one type of practical problem in which Dr. Paschkis has electrically repeated some tests previously run on the West Coast with a cork-insulated pipe intermittently heated by steam. This problem has practical importance because a pipe heated half the time loses considerably more than half the heat that would be lost from a pipe heated all the time, particularly if the heating intervals are short.



NINE OF THE 15 SECTIONS ARE HERE VISIBLE. NOTE INSTRUMENTS AND CONTROLS AT CENTER.

Dr. Paschkis set up the proper resistances and capacities for the pipe and the imaginary layers of the cork. Since he worked from steam temperature inside to air outside he set up at *A* and *G* electrical resistances only (no capacities) representing the boundary heat resistances (from steam to metal and from cork to air). His electrically plotted curves almost exactly reproduced those laboriously obtained with thermocouples buried in the actual cork insulation. In a few minutes the electrical solution reproduced days of experimental work.

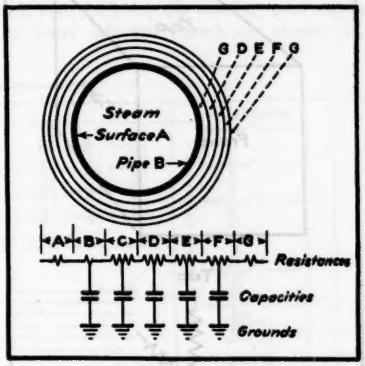


FIGURE 3.—SETUP TO DETERMINE TEMPERATURES AND HEAT LOSSES WHEN A CORK-INSULATED PIPE IS ALTERNATELY STEAM HEATED AND COOLED. THIS MODEL QUICKLY CHECKED THE CURVES OBTAINED BY ACTUAL TEST ON THE INSULATED PIPE.

The problems explained so far have been handled as cases of heat flow in a single dimension. For 3-dimensional thermal problems the body must be broken down into a series of pieces, each of three dimensions. Each such piece may be a cube (Figure 4) or any other convenient shape. If the shape is a cube and the material is homogeneous, its heat resistance is the same along the three intersecting resistances. To their center point is connected a condenser whose capacity is equal to the heat capacity of the piece. We then have the complete electrical counterpart of the heat properties of the piece. Such electrical counterparts can then be connected to simulate the entire body to be "tested."

So far, in this discussion, it has been implied that a temperature difference of 1000 F. would be represented by 1000 volts, a heat capacity of 50 Btu. per degree F. by 50 Farads, a heat-flow time of one hour by one second of electrical flow, one Btu. by one Coulomb of electrical charge and one Btu. per hour by one ampere. Obviously such one-to-one ratios might involve electrical and time values not convenient for laboratory testing. As a matter of fact the electrical values used in actual testing are juggled considerably for the sake of convenience. This introduces no error if cer-

tain relations are maintained and proper conversion factors are used. The mathematical method is explained in the A.S.M.E. paper compiled by Messrs. Paschkis and Baker.

The machine or apparatus (Dr. Paschkis calls it the "model") shown in the photographs differ greatly from the original apparatus of Beuken of

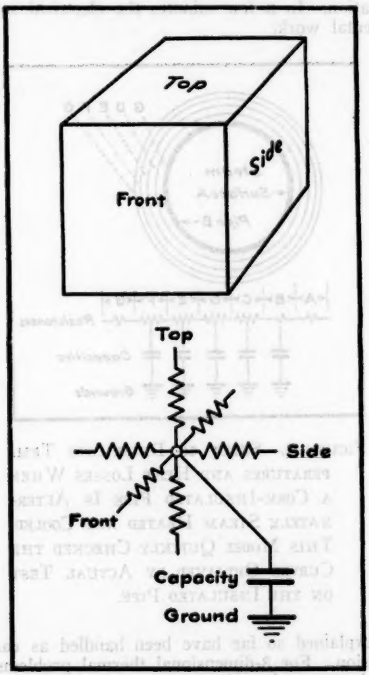


FIGURE 4.—FOR 3-DIMENSIONAL FLOW THE ORIGINAL HEAT-TRANSFER STRUCTURE MUST BE DIVIDED INTO PIECES OF CUBICAL OR OTHER SHAPE. RESISTANCE TO HEAT FLOW CAN BE REPRESENTED BY THE THREE RESISTANCES AND HEAT CAPACITY BY A GROUNDED CONDENSER.

Holland. Most important improvements are arrangements for changing the capacity during the experiments and for automatically recording the voltages.

The equipment is in fifteen sections, each of which may represent one section of the original heat-transfer structure. Each section has six trays of condensers ranging in capacity from 0.1 microfarad to 20 microfarad. In

any section it is possible to plug in any capacity from 0.1 microfarad to 152 microfarad by steps of 0.1. All these condensers are accurate to within plus or minus one per cent and the insulation resistance is at least 15,000 megohms per microfarad to prevent appreciable loss of charge from the condensers during the period of a test. There are 525 condensers in the entire apparatus.

Figure 5 shows the electrical connections of one of the 15 sections. Circles represent plug holes for jack connections. At upper left note the six trays of condensers, one side of each grounded. On resistor board at right is set up the electrical resistance for the section, anything from 100 ohms to 1,111,000 ohms. At lower left and center are shown the plug-board and

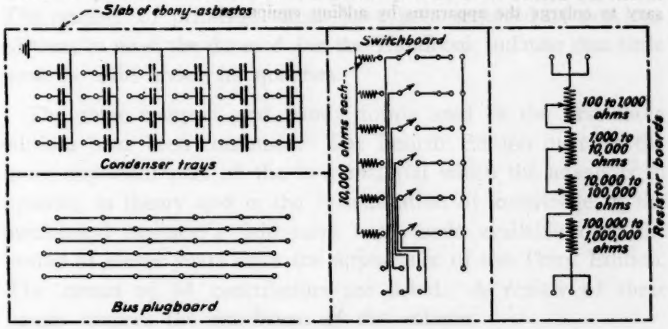


FIGURE 5.—WIRING DIAGRAM OF ONE OF THE 15 SECTIONS. ON THIS, PROPERTY RESISTANCE AND CAPACITY ARE PLUGGED IN TO REPRESENT ONE SECTION OF THE ORIGINAL HEAT-TRANSFER STRUCTURE.

switchboard of the section, through which the condensers can be properly connected to the resistances and the whole to the other sections.

The condensers may be combined into six groups by plugging from the flexible plugboards on the trays to the busboard. It is also possible to connect condensers of one section to the busboard of another. Ten busses run along the top of the installation of resistor and condenser sections, so that any of the instruments may be plugged to any of the sections. For the 15 sections several thousand plug connections are available.

Power controls and the instruments are mounted on a central panel. A special unit plugged in on the local 110-volt AC. current delivers constant-voltage DC. at any desired potential from 286 volts down, so that voltage may be set up corresponding to the temperature difference under consideration.

If desired, the equipment may be set for automatically controlled constant-current flow rather than for constant voltage, thus simulating the condition of constant heat flow with varying temperature difference. Specially developed electronic voltmeters are used to measure the potential (corresponding to temperature) in the various sections—also an electronic ampere-minute meter which measures charge in coulombs (corresponding to heat in Btu.).

While interesting, these details are of less interest than the fact that there is now available in America a machine that can quickly solve almost any problem of the flow of heat in solid materials, however complex the shape or irregular the heating conditions. It should find useful application in the following fields, among others: Refrigeration, quick freezing, welding, heat insulation, furnace walls, electric heating, process work, building walls, internal-combustion engines (pistons, walls, jackets), foundry work, ingot casting, billet heating and so on.

The only limitation on the type of problem that can be solved seems to be the size of the electrical machine. Having fifteen sections at present, it can be used to duplicate any heat-transfer structure that can be suitably represented by fifteen divisions. If the shape is so irregular that more than fifteen are needed for a suitably accurate solution, it will normally be necessary to enlarge the apparatus by adding equipment.

BOOK REVIEWS.

MARK'S HANDBOOK. The fourth edition of this most valuable aid to the Engineer came off the press in August, 1941. The number of printings which have been required of previous editions to meet the demand for the Handbook indicate that little need be said about its qualities.

The same compact and handy forms used in the first three editions have been continued. The Fourth Edition includes the more important part of the new material which the advances in practice, in theory and in the systemization of knowledge in the mechanical engineer's field have been made available over the period of eleven years since the appearance of the Third Edition. The names of 84 contributors are listed. A review of these names assures the excellence of the volume.

Published by McGraw-Hill Book Company, Inc.

1942 THE RADIO AMATEUR'S HANDBOOK. The American Radio Relay League presents the 19th edition of the Radio Amateur's Handbook. This volume is bound in an inexpensive cover and sells for $1.00.

The Handbook is arranged in four sections:

Introduction
Principles and Design
Construction and Data
Operating and Traffic Handling

These section headings indicate the scope of the volume whose 446 pages are replete with illustrations.

PRACTICAL MARINE DIESEL ENGINEERING. By L. R. Ford. Here is the Third Edition of a volume designed as an aid to operating marine Diesel engineers. It contains all of the theory which is essential to the understanding of what the operator is doing but does not go to the extent of discouraging the practical operator by attempting to cover the design engineer's field as well.

There are 581 pages tastefully printed and well illustrated. The first three chapters are devoted to theory covering action of gases and the heat and mechanical cycles. These are followed by 5 chapters which describe construction of typical Diesel marine engines. Five more chapters describe typical modern marine installations of diesel propulsion plants. The remainder of the book, 17 chapters, covers the operation of Diesel plants, including derangements, repairs, fuels and the requirements for obtaining a license as a Motorship Engineer.

The book should be of particular value in these days when the expansion of the American Merchant Marine under conditions of war is demanding the recruitment of many Diesel operators.

Published by Simmons-Boardman Publishing Corporation, 30 Church Street, New York, N. Y.

PAUL BAXTER DUNGAN

Rear Admiral Paul Baxter Dungan, U. S. Navy, was born on July 21, 1877 in Hastings, Nebraska, and died at the U. S. Naval Hospital, San Diego, on November 26, 1941. He attended the various schools of Nebraska and on September 6, 1895, at the age of eighteen years, he was appointed to the U. S. Naval Academy as a naval cadet, there taking the line course. Due to the exigencies of the services, the Spanish-American War having been underway, his class was graduated in January, 1899, and ordered to sea immediately, passed Midshipman Dungan being ordered to the hospital ship *Solace,* then on Asiatic station, he served successively on the *Baltimore, Panay and New Orleans.*

While on the latter ship he was commissioned ensign in 1901, and in the following year returned to the United States to take up duties on the battleship *Alabama.* His first specific command was the submarine torpedo boat *Shark* in 1904, stationed at Guantanamo Bay, Cuba. The following year he again went to the Pacific for duty, this time to Tutuila. Four years later he returned as recruiting officer in Omaha, Nebraska, his home state, leaving from there for another Asiatic tour, this time as fleet engineer on the staff of the Commander-in-Chief of the Asiatic Squadron.

Returning again to the mainland he assumed the duties of Engineer-in-Charge of the Machinery Division in the Navy Yard, New York, where he served from January, 1914, to November, 1920. His next important duty was as Officer-in-Charge of the Engineering Experiment Station at Annapolis from 1923 to 1926, after which followed a tour of duty at the Navy Yard, Pearl Harbor.

This was succeeded by a tour of duty as manager of the Navy Yard, New York, for a period of almost five years during which he was promoted to the grade of rear admiral. Shortly there-

after he was ordered to the Bethlehem Shipbuilding Company's Fore River Plant for duty as inspector of machinery from there proceeding to the West Coast to be inspector of naval material at San Francisco where he remained until his retirement in January, 1941.

Seven months after he retired, Admiral Dungan was recalled to duty as Inspector of Naval Material at Los Angeles. He was not destined to remain long for shortly thereafter he entered the naval hospital at San Diego where he crossed the line leaving as his survivors, his wife, Mabel Miller Dungan, a daughter and many friends in all walks of life, both naval and civil, that his pleasant personality had gained.

Admiral Dungan joined the Society on March 5, 1914, and continued his membership until his death.

ASSOCIATION NOTES.

OFFICERS, 1942.

The following were elected officers of the Society for the calendar year 1942:

President:

Rear Admiral Herbert S. Howard, U. S. N.

Secretary-Treasurer:

Commander James E. Hamilton, U. S. N.

Member of Council:

Rear Admiral Bryson Bruce, U. S. N.
Captain H. E. Saunders, U. S. N.
Captain L. F. Small, U. S. N.
Captain E. W. Mills, U. S. N.
Commander W. J. Kossler, U. S. C. G.
Mr. Roger Williams.
Mr. James Bates.

AMENDMENT OF BY-LAWS.

The changes in the By-Laws of the Society, Article 13, to incorporate Life Members in the Memberships available and Article 14, to provide that persons qualified as Naval and Civil Members shall be eligible for life membership on his application and payment of $150.00, have been adopted by vote of the membership.

BANQUET.

Because of the emergency which confronts us all, with the extreme pressure upon both Naval and Civilian personnel throughout the engineering field, the Council has decided with the utmost regret and disappointment that no banquet of the Society will be held in 1942. It is the earnest wish that the occasion may be resumed in the near future.

MEMBERSHIP.

The following have joined the Society since the publication of the November, 1941, issue of the Journal:

NAVAL.

Bedford, Stephen R., Lieut. Commander, U. S. N.

Caskey, M. W., Lieutenant, U. S. C. G.

DeCarlo, Joseph J., Lieutenant, U. S. C. G.

Downey, Dr. John Otho, General Motors Corp., 1775 Broadway, New York, N. Y.

Eppinger, Pearson J., Lieutenant, U. S. N. R., U. S. S. *Anteaus.*

Fredette, Joseph R., Lieutenant, U. S. C. G.

Frick, Duncan W., Lieutenant, U. S. N. R., 504 North Elm Drive, Beverly Hills, Calif.

Gill, Percy O., Lieutenant, U. S. N. R., Standard Oil Co. of N. J., Marine Dept., Foot East 22d St., Bayonne, N. J.

Goodwin, Clyde D., Lieutenant, U. S. C. G.

Halstead, George Chappel, Ensign, U. S. N. R., Resident Inspector in Charge, Brown Shipbuilding Co., Houston, Texas.

Harrison, Robert E. M., Lieut. Commander, U. S. N. R., Bureau of Ships, Navy Department.

Hoopes, Robert D., Jr., Ensign, U. S. N. R., Submarine Base, New London, Conn.

Humphrey, Howard C., Ensign, U. S. N. R., 1465 Pierson College, Yale University, New Haven, Conn.

Judd, Neil, Ensign, U. S. N. R.

Larson, Carl W., Lieut. Commander, U. S. N. R., Bureau of Ships, Navy Dept.

Meyer, George H., Boatswain, U. S. C. G., 6442 Raymond St., Oakland, Calif.

Schweichert, C. E., Ensign, U. S. N.

Waters, Marshall, Lieutenant, U. S. N. R., Navy Yard, Pearl Harbor, T. H.

Wylie, Harold, Chf. Machinist, U. S. C. G., 3041 Halcyon Court, Berkeley, Calif.

CIVIL.

Ackerman, Harold P., Sales Engineer, American Car and Foundry Co., 30 Church St., New York, N. Y. Mail, 5245 Apache Ave., Drexel Hill, Pa.

Boehly, Henry William, Senior Marine Engineer, Bureau of Ships, Navy Dept. Mail, 4669 South 4th St., Arlington, Va.

Buck, Harold F., President, Industrial Engineering Corporation, 1201 Barr Building, Washington, D. C.

Coffin, LeRoy, Electrical Design Engineer, Allis Chalmers Mfg. Co., Milwaukee, Wis. Mail, 2121 Virginia Ave., N.W., Washington, D. C.

Converse, Ward, Special Representative, Crane Company, 1225 Eye St., N.W., Washington, D. C.

Eger, Charles H., Marine Superintendent, General Electric Co., Philadelphia District, 1405 Locust St., Philadelphia, Pa.

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Jensen, Gunnar, Chief Engineer, Walker Mfg. Co. of Wisconsin, Walker Michigan Division, Jackson, Mich.

Klemgard, Edwin N., Senior Technologist (Petroleum), U. S. Experiment Station, Annapolis, Md. Mail, Arnold, Md.

Oneal, Lloyd E., Engineer and Sales Representative, 15 Exchange Place, Jersey City, N. J. Mail, 602 Raymond St., Westfield, N. J.

Osborne, Alan, Senior Marine Engineering Assistant, Chief Engineer Design Specifications & Priority Section, Technical Div., U. S. Maritime Commission, Room 4222 Commerce Bldg., Washington, D. C.

Smith, Percy L., Engineering Manager, Weaver Associates Corporation, 3 Dupont Circle, Washington, D. C. Mail, Apt. 716, The Granite State Apartments, 1739 New Hampshire Ave., N.W., Washington, D. C.

Spooner, Albert P., Metallurgical Engineer, Bethlehem Steel Company, Bethlehem, Pa.

ASSOCIATE.

Bloomfield, Roger C., Engineer, Marine Division, Mason-Neilan Regulator Co., 1190 Adams St., Boston, Mass.

Else, Ralph F., Associate Engineer, care American Locomotive Co., Auburn, N. Y.

Garfinkel, Bernard, Asst. Marine Engineer, Planning Division, Navy Yard, New York, N. Y. Mail, 779 Howard Ave., Brooklyn, N. Y.

Jameson, Albert S., Junior Engineer, Machinery Scientific Division, Gibbs & Cox, Inc., 21 West St., New York, N. Y.

Keyes, Raymond E., Instructor, Dept. of N. A., Massachusetts Institute of Technology, Cambridge, Mass. Mail, 19 Irma Ave., Watertown, Mass.

Langenberg, J. W. A., Officer van der Marinegtoom Vaartdienst der Za Klasse, Ondarzeedienst Soerabaja, Ned. India.

Parrett, Henry T., Manager Government & Marine Depts., Vapor Car Heating Co., Inc., Investment Building, Washington, D. C.

Pinochet, Jorge, M. TTE 1° Ing. Marina De Chile Acorazado *Lattore,* Valparaiso, Chile.

Zelman, Frederick, Machinery Scientific Div., Gibbs & Cox, Inc., 21 West St., New York, N. Y. Mail, 7 Veronica Place, Brooklyn, N. Y.